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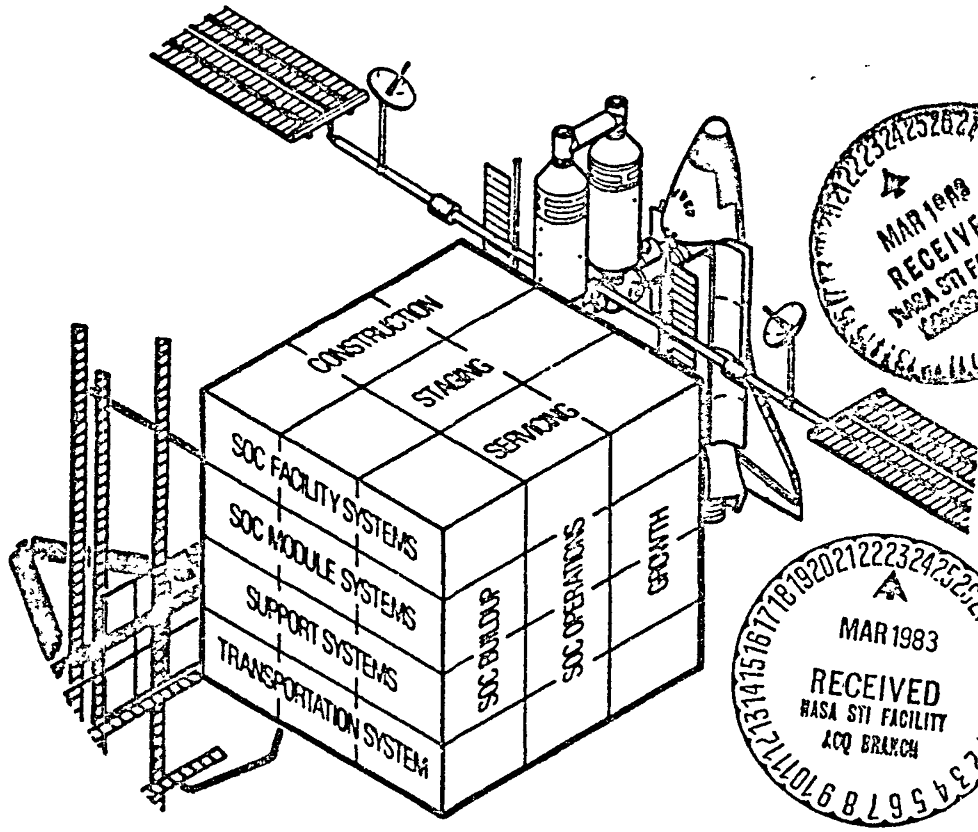
SPACE OPERATIONS CENTER — SHUTTLE INTERACTION STUDY (NAS9-16153)

SSD 81-0076

FINAL REPORT

EXECUTIVE SUMMARY



DRL T-1626

LINE ITEM 3

April 17, 1981

Space Operations and Satellite Systems Division
Rockwell International

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SPACE OPERATIONS CENTER/SHUTTLE INTERACTION STUDY

FINAL REPORT, EXECUTIVE SUMMARY

Contract No. NAS9-16153
DRL T-1626
Line Item 3

April 17, 1981

Approved by A. J. Stefan
A. J. Stefan

Rockwell International
Space Operations and
Satellite Systems Division

FOREWORD

This report contains the results of the analysis that was performed to determine the implication of using the Shuttle with the Space Operations Center (SOC).

This effort was performed under Contract Number NAS9-16153, by the Space Operations and Satellite Systems Division of Rockwell International for the National Aeronautics and Space Administration, Johnson Space Center. The study was administered under the technical direction of the Contracting Officers Representative (COR), Mr. S. H. Nassiff, Program Development Office, Engineering and Development Directorate, Johnson Space Center.

The study was performed under the direction of Ellis Katz and A. J. Stefan, Study Managers. The following persons made significant contributions to the completion of the analysis.

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INTRODUCTION

The Space Operations Center (SOC) is conceived as a permanent facility in low earth orbit incorporating capabilities for space systems construction; space vehicle assembly, launching, recovery and servicing; and the servicing of co-orbiting satellites.

The Shuttle Transportation System (STS) is an integral element of the SOC concept. It will transport the various elements of the SOC into space and support the assembly operation. Subsequently, it will regularly service the SOC with crew rotations, crew supplies, construction materials, construction equipment and components, space vehicle elements, and propellants and spare parts.

This report contains the results of the study that analyzed, in a preliminary fashion, the implication of using the Shuttle with the SOC, including constraints that the Shuttle will place upon the SOC design. The study identifies the considerations involved in the use of the Shuttle as a part of the SOC concept, and also identifies the constraints to the SOC imposed by the Shuttle in its interactions with the SOC, and on the design or technical solutions which allow satisfactory accomplishment of the interactions.

STUDY TASKS

Five specific task areas were identified for study. These tasks are indicated in Table I-1 along with the principal issues associated with each task.

TABLE I-1 STUDY TASKS

TASK	ISSUES
1.0 ORBITAL ALTITUDE	• AT WHAT ALTITUDE SHOULD THE SOC OPERATE WHILE BEING COMPATIBLE WITH THE SHUTTLE CAPABILITIES?
2.0 BERTHING AND/OR DOCKING	• IS A STANDARD BERTHING/DOCKING INTERFACE FEASIBLE? • CAN THE ORBITER DOCK TO THE SOC? • CAN THE ORBITER BERTH TO THE SOC USING THE RMS?
3.0 SOC ASSEMBLY	• WHAT EQUIPMENT AND OPERATIONS ARE REQUIRED FOR THE SHUTTLE TO ASSEMBLE THE SOC? • WHAT ARE THE IMPLICATIONS TO THE SOC ELEMENTS?
4.0 SOC RESUPPLY AND FUEL TRANSFER	• WHAT ARE THE IMPLICATIONS OF SOC RESUPPLY VIA THE LOGISTICS MODULE AND THE SHUTTLE? • WHAT ARE THE IMPLICATIONS OF TRANSFERRING PROPELLANTS FROM THE SHUTTLE TO THE SOC? • DEVELOP A SHUTTLE LOGISTICS MODEL
5.0 FLIGHT SUPPORT FACILITY	• WHAT ARE THE IMPLICATIONS TO THE SOC TO PROVIDE SPACECRAFT SERVICING? • WHAT ARE THE IMPLICATIONS TO THE SHUTTLE TO PROVIDE SPACECRAFT SERVICING? • WHAT ARE THE SPACE-BASED VEHICLE REQUIREMENTS?

SPACECRAFT CONFIGURATIONS

The reference SOC configuration supplied by NASA/JSC was utilized as the model for this study, Figure I-1. Changes to the configuration were only imposed when the task implications so indicated. Two OTV concepts were utilized as models for the analysis, a parallel stage arrangement that was developed from the manned OTV study by Grumman Aerospace Corporation for NASA/JSC, Figure I-2, and a tandem stage concept, Figure I-3, developed from the Future OTV Technology Study by Boeing Aerospace Corporation for NASA/LARC. Basic configuration and operational characteristics of the OTV stages were mutually developed with Rockwell International, Boeing Aerospace Corporation, and NASA/JSC. These characteristics are listed in Section 5.0 Flight Support Facility.

REPORT ORGANIZATION

This report is organized into five basic sections that correspond to the five tasks previously described. A conclusion section will summarize the implications to the SOC and to the orbiter, and will describe the requirements imposed on the OTV as a result of the space based servicing operations.

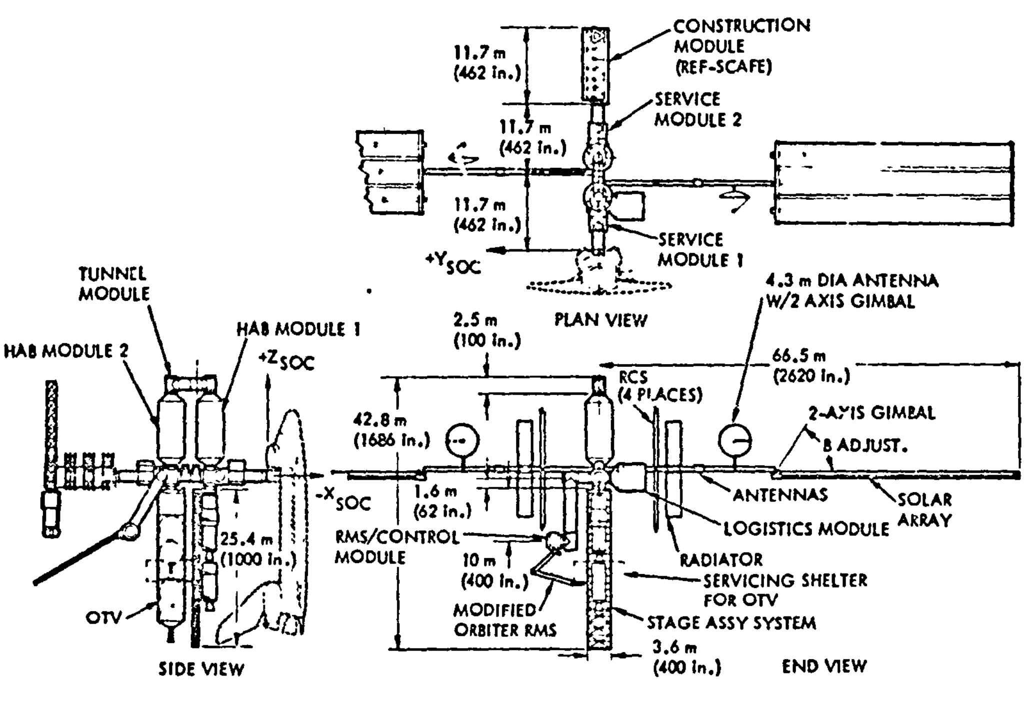

FIGURE I-1 SPACE OPERATIONS CENTER REFERENCE CONFIGURATION

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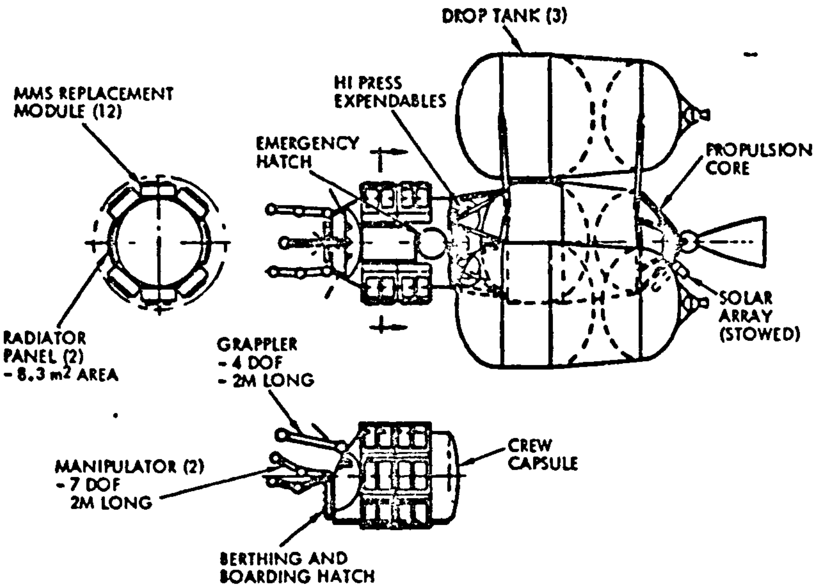

FIGURE I-2 MOTV GEO TRANSFER CONFIGURATION

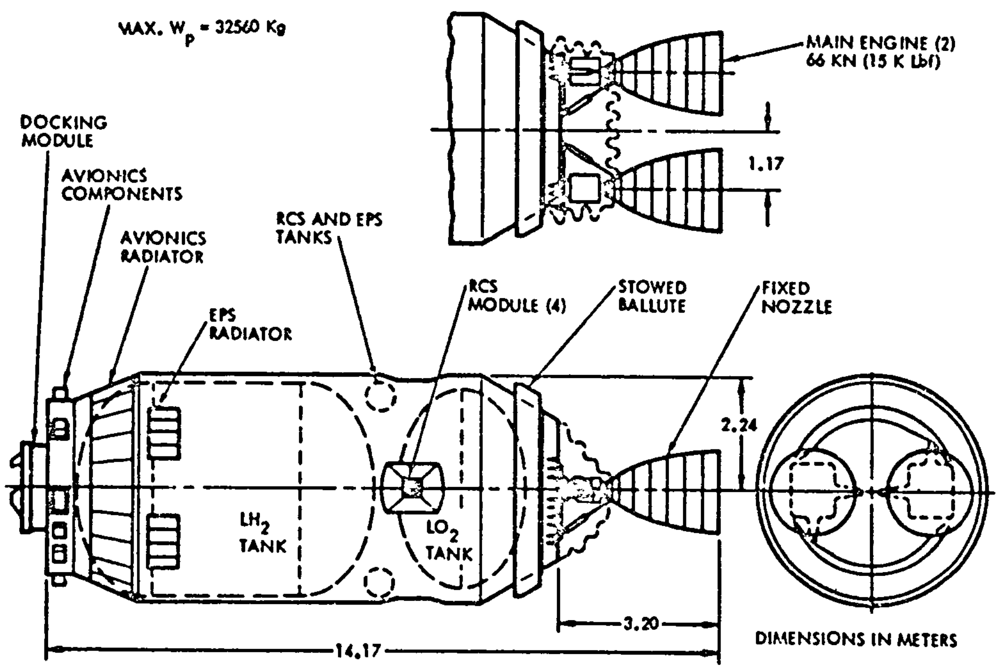

FIGURE I-3 SPACE-BASED OTV CONFIGURATION

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1.0 ORBITAL ALTITUDE

The Space Operations Center (SOC) is planned as a versatile permanently manned base in low earth orbit. The space shuttle will resupply the SOC on a regular basis to support a wide variety of missions. Orbit transfer vehicles (OTV) will be refueled and serviced at the SOC to carry payloads on missions to higher energy orbits and large space systems, too large for single flight delivery in the orbiter bay, will be erected, assembled and/or constructed on special SOC facilities.

The size, complexity and value of the Space Operations Center and the associated space systems requires that a careful and detailed analysis be performed to determine preferred operating altitudes. The objective, therefore, is to seek out the most effective orbit altitude strategy for the SOC which utilizes the maximum potential of the Space Shuttle and at the same time provides adequate safety and an efficient operating base for staging OTV missions.

1.1 SOC ALTITUDE

There are a number of factors which can influence the selection of SOC orbit altitude. The most prominent of these are shown symbolically in Figure 1.1. The nature of their effects are highlighted in the following discussion. First, the delivery system performance for SOC resupply is of obvious importance. Payload performance drops off with altitude for all launch systems and affects the number of flights required to deliver a given amount of cargo. Thus, the specific performance characteristics of the standard shuttle and later thrust augmented versions as well as other logistics modes such as tug assisted concepts can affect the desired SOC orbit altitude. Generally, the shallower the slope of payload drop off with altitude the higher the preferred operating orbit will be. This is because at the lower altitudes where payload delivery performance is high, the drag forces acting on the SOC are also high, thereby requiring large quantities of orbit makeup propellant.

The actual amount of required propellant and hence its importance in altitude determination is influenced by several factors. They are atmospheric density, which varies dramatically over the 11 year solar cycle period, the drag configuration of the SOC, which can also vary depending upon construction project and OTV activity levels, and the SOC propulsion system specific impulse. The balance between these two basic effects, delivery performance drop off at high altitudes and high drag makeup propellants at low altitudes, determine the optimum logistics altitude requiring the least number of delivery flights.

However, these factors are further influenced by the amount and nature of the SOC logistics traffic. High traffic levels mean the Shuttle delivery performance begins to outweigh the orbit makeup propellant effects on optimum altitude, and for high traffic levels the optimum altitude will be lower. The actual altitude will also be influenced by the packaged density

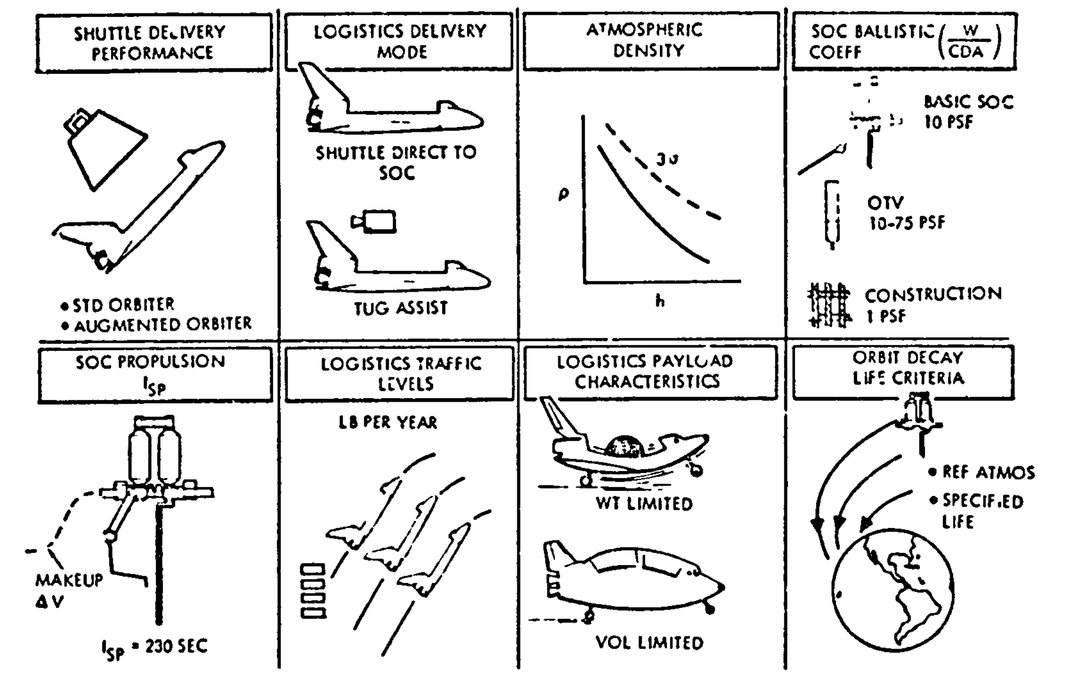

FIGURE 1.1 SOC ORBIT ALTITUDE FACTORS

characteristics of the logistics cargo. Volume limited cargo can be carried to higher orbit altitudes, thus putting a "bias" in the delivery performance effects on the optimum orbit altitude.

Superimposed on all of the above factors is the need for orbital safety. A specified orbit decay life criteria will set altitude limits, which at times, depending upon the actual criteria selected and the prevailing SOC logistics environment, may be the governing condition. Figure 1.2 indicates the decay safety altitude in relationship to the atmosphere density occurring in the 11 year cycle.

The analysis of these factors and their interactions resulted in the following principal conclusions which are highlighted below along with brief substantiating text.

<u>A Variable Altitude Strategy is Recommended for SOC Operation</u>

A variable altitude strategy as depicted in Figure 1.3 combines safety with logistics efficiency. During periods of unusually high solar activity the SOC orbit altitude would be adjusted upward to maintain the 90-day orbit decay life criteria required for orbital safety. However, most of the time, when solar activity levels follow their nominal 11 year cycle trends, the SOC altitude can be greatly reduced to take advantage of the greater shuttle payload delivery capability at low altitudes. This improves the logistics

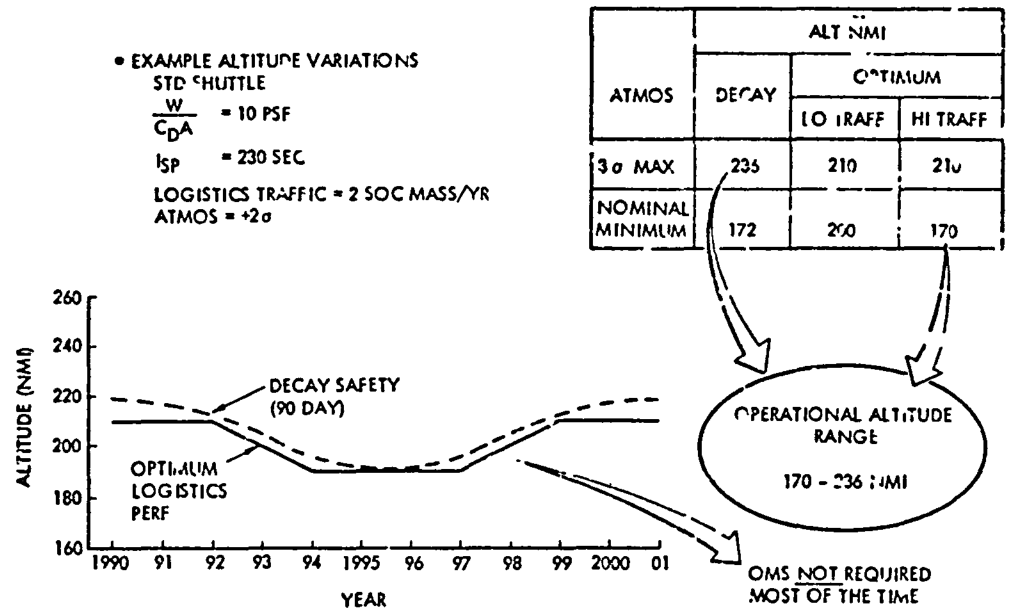

FIGURE 1.2 SOC OPERATIONAL ALTITUDE RANGE

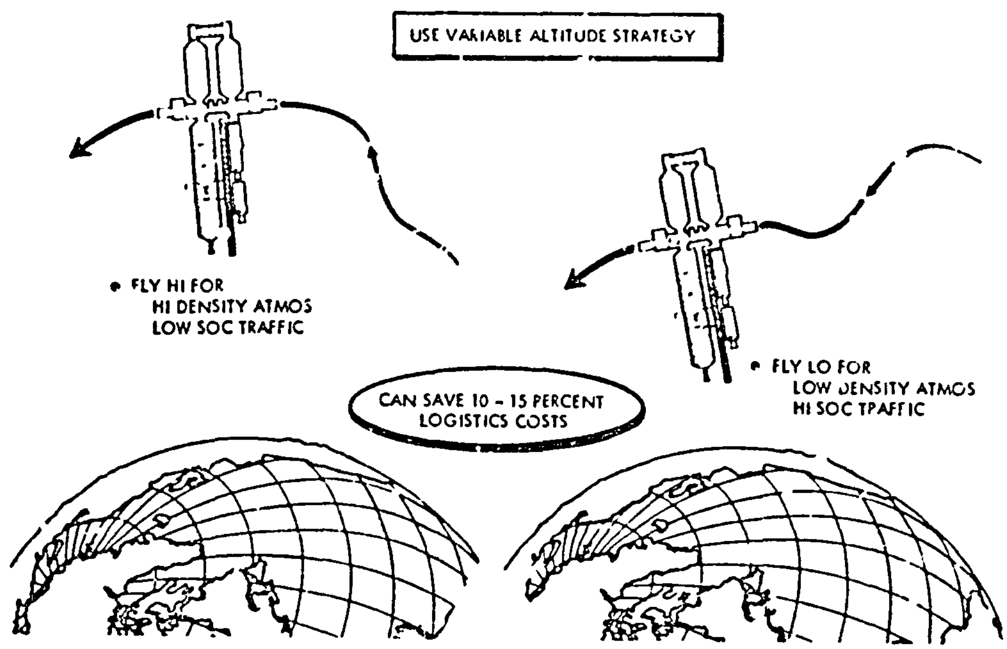

FIGURE 1.3 SOC ORBIT ATTITUDE STRATEGY

efficiency by reducing the number of shuttle flights required to deliver a given amount of SOC cargo. Further, the actual operating altitude can be optimized for the prevailing atmospheric density and amount of SOC logistics traffic scheduled. This variable altitude approach can save 10 to 15 percent in the number of required shuttle flights to SOC compared to a constant altitude concept which must be based on the worst case decay environment and hence must always fly at a high altitude. Thus, a variable altitude strategy is recommended.

1.2 SHUTTLE LOGISTICS DELIVERY

The Standard Orbiter can do the Job

The currently projected modular elements of the SOC configuration, such as the service modules, the habitability modules, etc., can all be delivered to orbit by the standard shuttle. These various modules, logically sized for their respective SOC mission roles, fit within the orbiter cargo bay and are well within the payload delivery capability of the standard shuttle. Normal SOC resupply, OTV propellants and other SOC cargo can also be delivered by the standard shuttle.

The extra payload capability of the thrust augmented shuttle is not needed for the delivery of the SOC modules. However, if cost effective in terms of dollars per pound to orbit, it may prove to be more efficient for OTV propellant deliveries, but even here the standard shuttle is sufficient. The optimum SOC altitude is about 18 Km (10 nmi) higher with the augmented thrust shuttle, but varies with logistics traffic levels and density in the same manner as the standard shuttle. Therefore, both the standard and augmented shuttles are compatible with the variable altitude strategy, Figure 1.4.

Thus, while gains in logistics efficiency for weight limited payloads such as OTV propellant deliveries may be attainable with the thrust augmented shuttle the standard shuttle can do an adequate job. A special new delivery system is not required for the SOC.

Direct Shuttle Delivery is the Recommended SOC Logistics Mode

Three basic SOC logistics modes were investigated, Figure 1.5. They are: (1) direct shuttle delivery in which all cargo is carried direct to the SOC in the orbiter bay, (2) tug assisted delivery in which all SOC cargo plus tug propellants are delivered by the Shuttle to 275 Km (150 n.mi, maximum shuttle altitude with 55K lb. payload) where they are transferred to a SOC based tug for subsequent delivery to the SOC and (3) an OTV flydown mode where the basic SOC resupply cargo is still delivered direct to SOC by the shuttle, but OTV propellants and payloads are delivered to 275 Km where they are transferred to an OTV which was earlier flown down from the SOC. In this mode the OTV always returns to the SOC for servicing after a GEO mission and is flown down to the 275 Km refueling altitude at the beginning of the next mission.

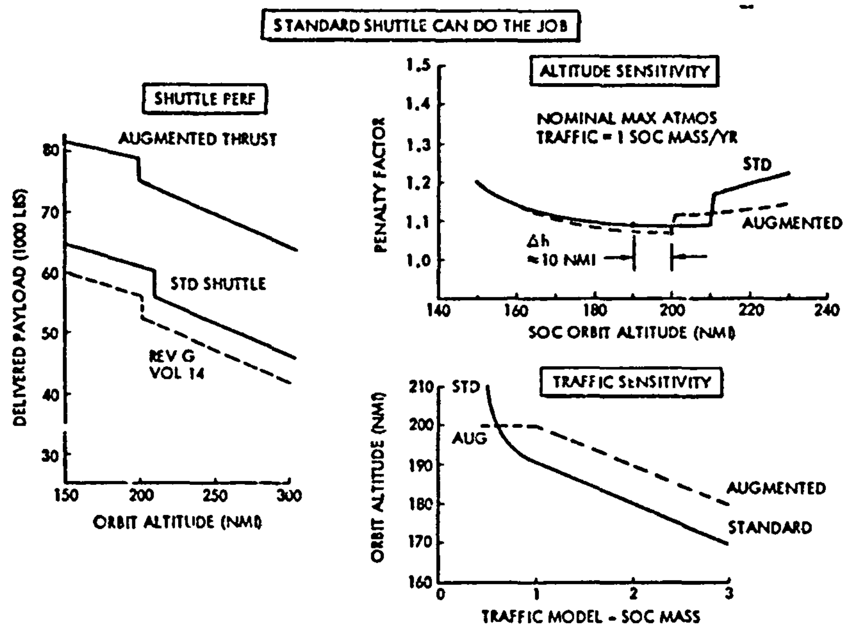

FIGURE 1.4 DELIVERY PERFORMANCE COMPARISON

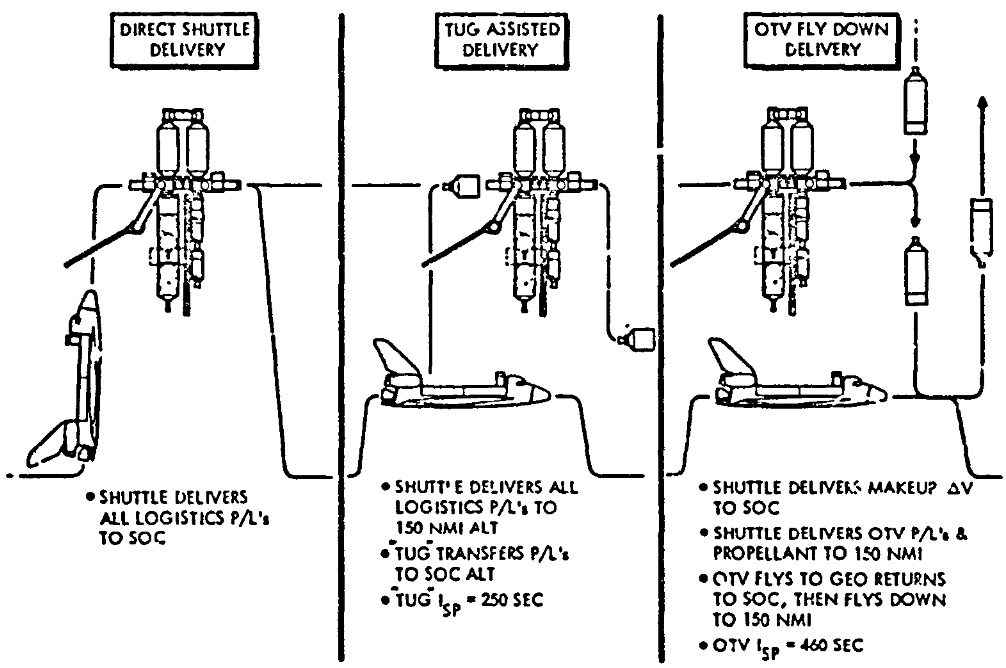

FIGURE 1.5 SOC LOGISTICS MODE OPTIONS

The overall logistics performance of these three modes is nearly equal (less than 2% spread) over a wide range of traffic levels, Figure 1.6. The extra rendezvous ΔV's for the tug mission profile and the occasional extra shuttle flight to return the tug for ground refurbishment nearly negates the theoretical gains from not flying the he vy orbiter all the way to SOC altitudes. Similar negating factors occur with the OTV flydown mode including the extra ΔV required to stage GEO missions from 275 Km over that from higher altitudes.

Thus, because of the nearby equal performance of all modes and the major operational complexities introduced by the alternative modes, direct shuttle delivery is recommended for SOC.

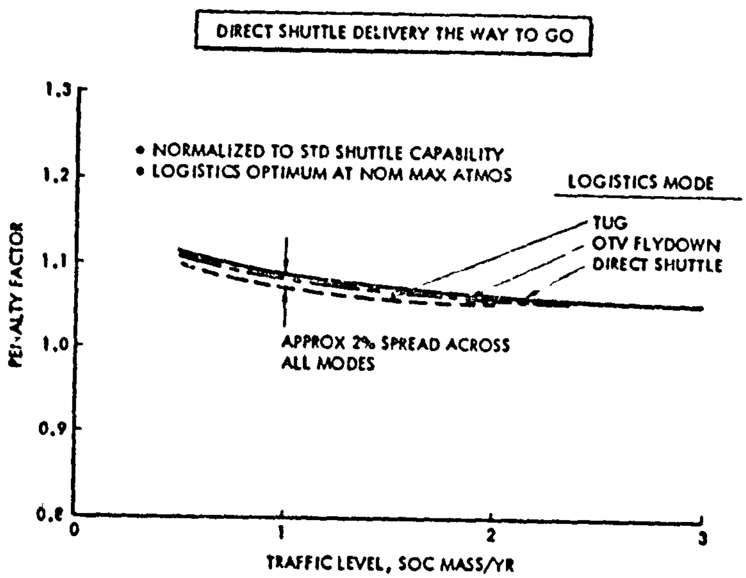

FIGURE 1.6 DELIVERY MODES COMPARISON

2.0 BERTHING & DOCKING

The objective of Task 2.0 is to explore the SOC/Shuttle interactions related to berthing and docking in order to (1) assess the suitability of the orbiter design for performing these types of operations in conjunction with a large orbiting system, (2) identify key safety related issues, (3) drive out any special SOC requirements introduced by the berthing or docking processes, and (4) analyze the orbiter-SOC docking interfaces for potential commonality with other user programs.

Toward this end, the ability of the orbiter to safely perform terminal closure and docking with SOC was investigated including a number of factors affecting trajectory accuracy, major plume impingement effects and RCS jet failure implications. The key findings from this investigation are underlined in the following paragraphs and accompanied by brief substantiating text.

2.1 DOCKING OPERATIONS

<u>The Orbiter Can Dock With The SOC</u>

The orbiter flight control system is capable of translation and rotational control accuracies of ±0.015MPS (±0.05FPS) and ±0.2 deg per sec respectively which are well within the limiting docking contact conditions specified for SOC, Table 2.1. Also, there is sufficient thrust/control authority to counter the gravity gradient, aero and other disturbance forces and torques encountered during the docking maneuver sequence. Thus, under normal conditions the orbiter can safely dock with the SOC. Figure 2.1 illustrates a normal docking approach and also identifies the capability of the orbiter's reaction control system to perform the docking maneuver.

FIGURE 2.1 DOCKING CONTACT REQUIREMENTS

AXIAL CLOSING VEL	0.05 (0.15 MPS (0.16-0.5 FPS)
LATERAL VEL	≤0.06 MPS (≤ 0.2 FPS)
ANGULAR VEL	≤0.6 DEG/SEC
LATERAL MISALIGNMENT	≤0.23M (≤ 0.75 FT)
ANGULAR MISALIGNMENT	≤5.0 DEG (ROLL)
	≤6.0 DEG (PITCH/YAW)

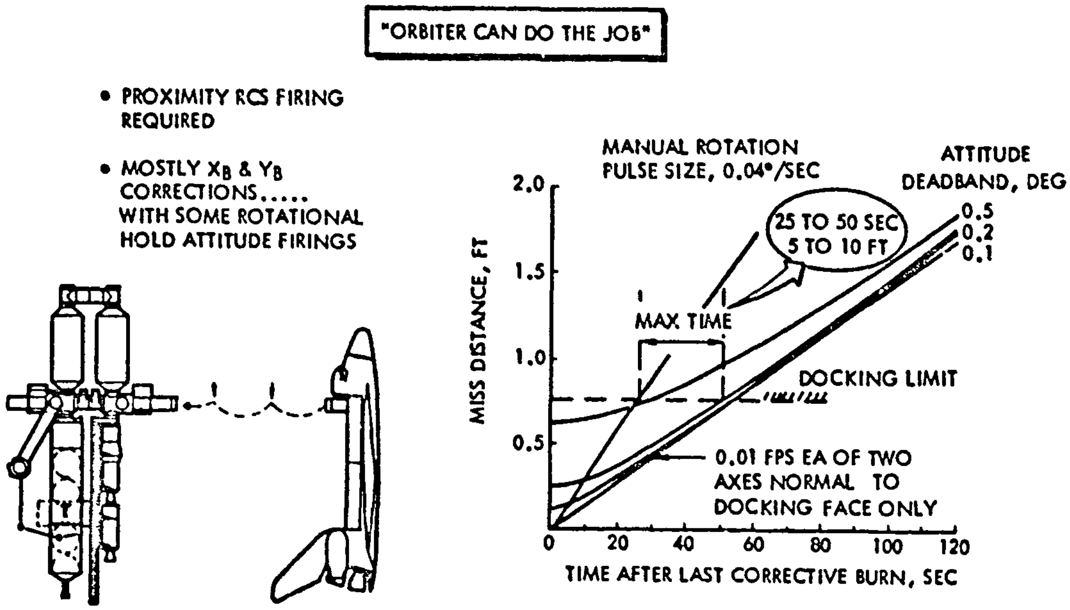

FIGURE 2.1 DOCKING TRAJECTORY ACCURACY

A Runaway Jet Poses A Serious Problem But Appears To Be Controllable With The "Hi-Z" RCS Thrusting Mode

The critical concern with a runaway jet is the case just before docking contact. Figure 2.2 indicates this critical zone area and compares its analogy to helicopter operations. Here, there is some danger of orbiter-SOC contact outside of the docking envelope. Deviations caused by a runaway jet could drive the orbiter outside of the docking envelope before an abort maneuver to reverse the closing velocity could be completed. However, with the "Hi-Z" thrusting mode the stopping/turnaround times as shown in Figure 2.3 are sufficiently small that deviations from any single runaway jet will always be within the safe docking envelope if the separation distance is within the turnaround envelope at the time of the jet failure. Under these conditions docking will occur with the failed jet still firing. For failures at separation distances greater than this value, safe turnaround aborts without orbiter-SOC contact can be made, Figure 2.4. Man-in-the-loop simulations with visual cues and system response characteristics are required to confirm this preliminary finding.

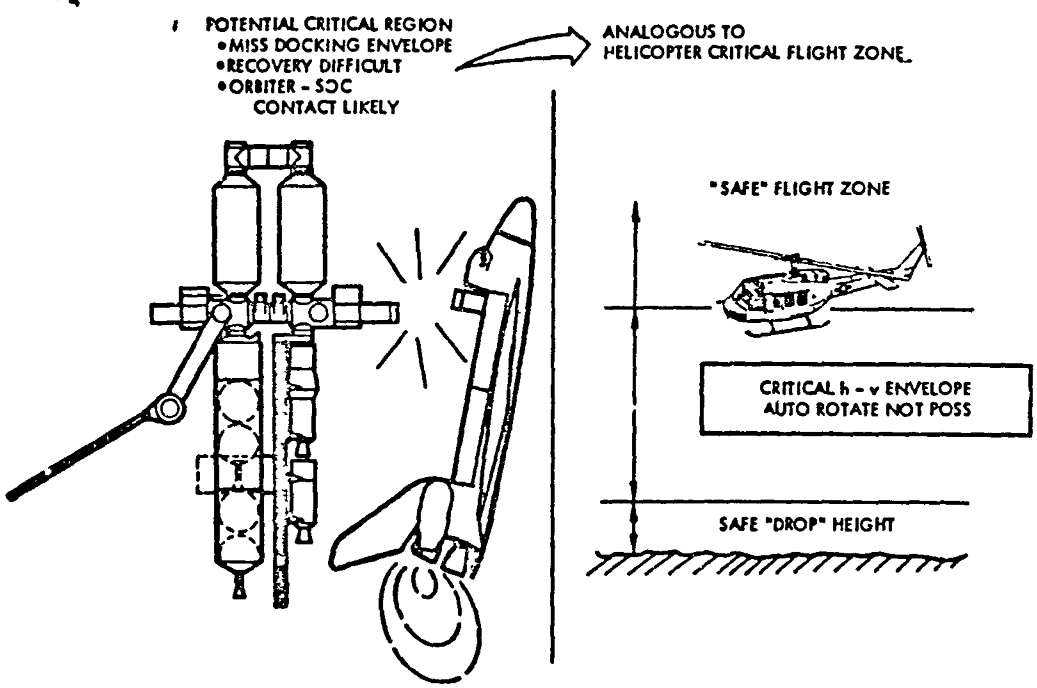

FIGURE 2.2 CRITICAL ZONE DEFINITION

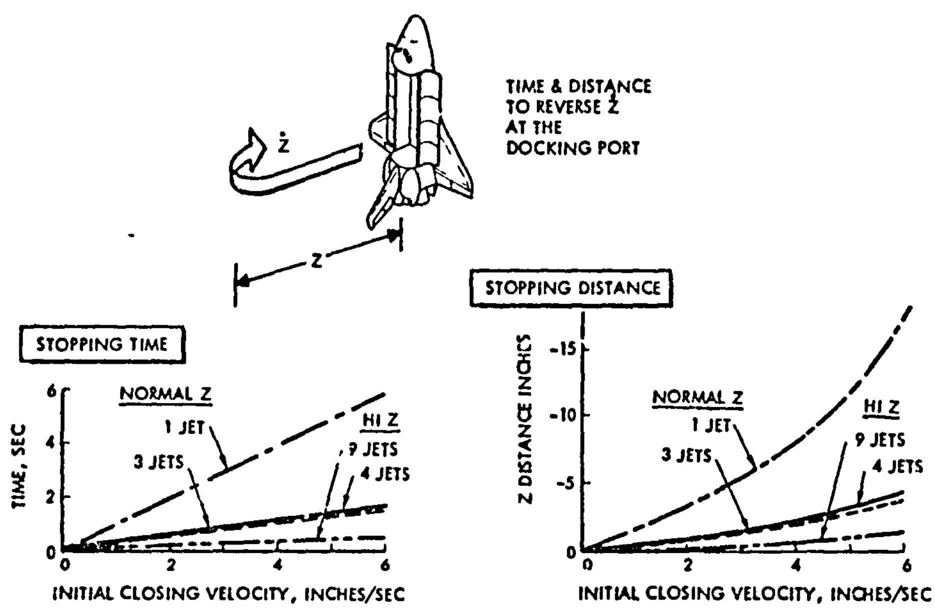

FIGURE 2.3 DOCKING ABORT TURNAROUND

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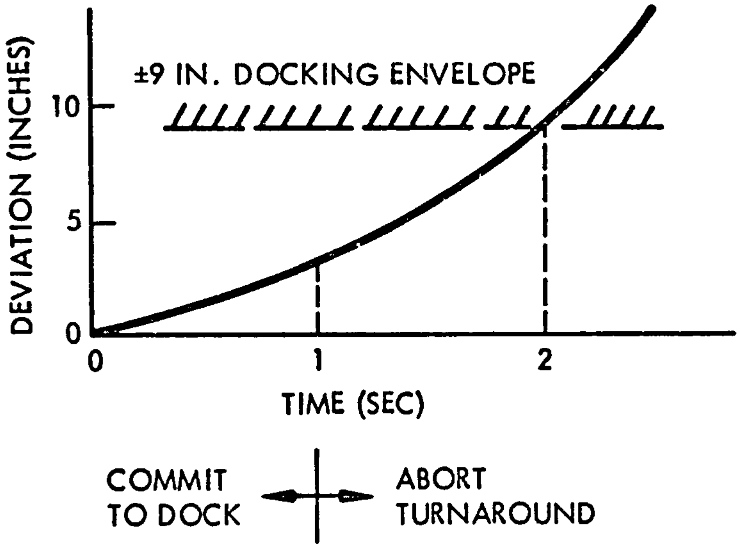

FIGURE 2.4 DOCK OR ABORT CRITERIA

A Failed "Off" Jet Is Not A Serious Problem

There is sufficient redundancy in the primary RCS system that no basic thrust a ıthority is lost with any single failed off jet. Hence, all maneuvers can be achieved without degradation. The only effect will be to introduce a 0.24 sec time delay (3 DAP sampling intervals, 80 milliseconds each) in the first thrusting action after the failure. The digital a•topilot (DA?) switches to the priority 2 jet in the affected jet group and all thrusting actions thereafter call for the use of this jet and no further 0.24 sec time delays occur. This can be seen in the thruster identification code of Figure 2.5 which shows that there are two to four thrusters in each of the 14 directional grou_ .

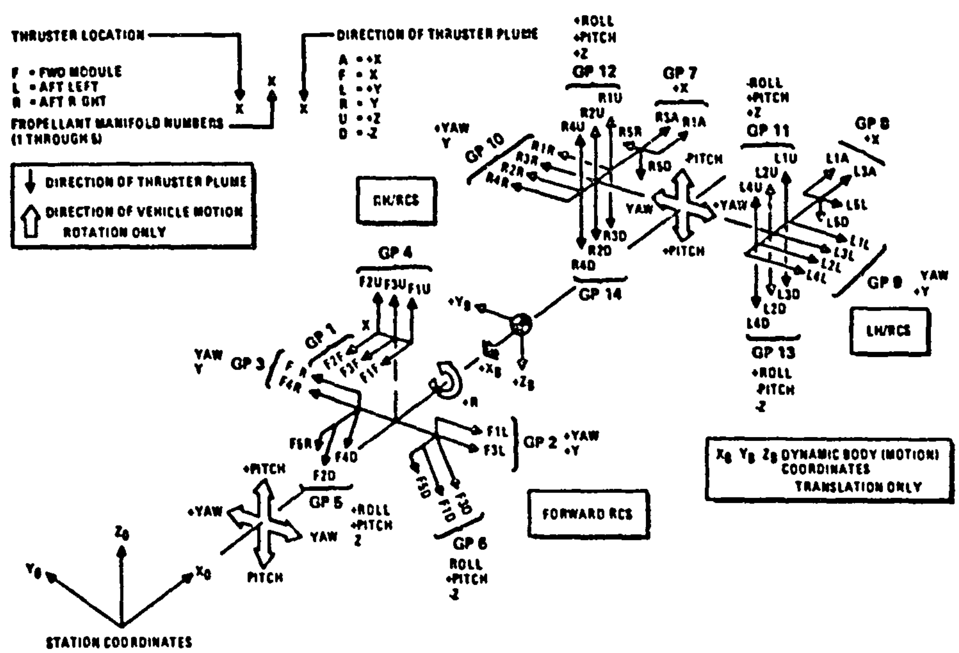

FIGURE 2.5 RCS THRUSTER IDENTIFICATION

<u>The SOC Should Be Designed For The Orbiter Docked Condition With Any Single RCS Jet In A Runaway Firing Condition</u>

As indicated above, if the runaway jet occurs just before docking contact is made a more or less normal docking hookup will be made with the jet still firing. If the runaway jet occurs anytime after this docking commitment point is reached up to the time the orbiter flight control system is disabled and powered down following normal docking the docked runaway jet condition is possible. It is estimated that up to one minute may be required to identify and shutdown a runaway jet. Thus, the recommendation to design the SOC for this condition is made. Two principal design conditions are identified in Figure 2.6 that need to be considered for this runaway jet condition.

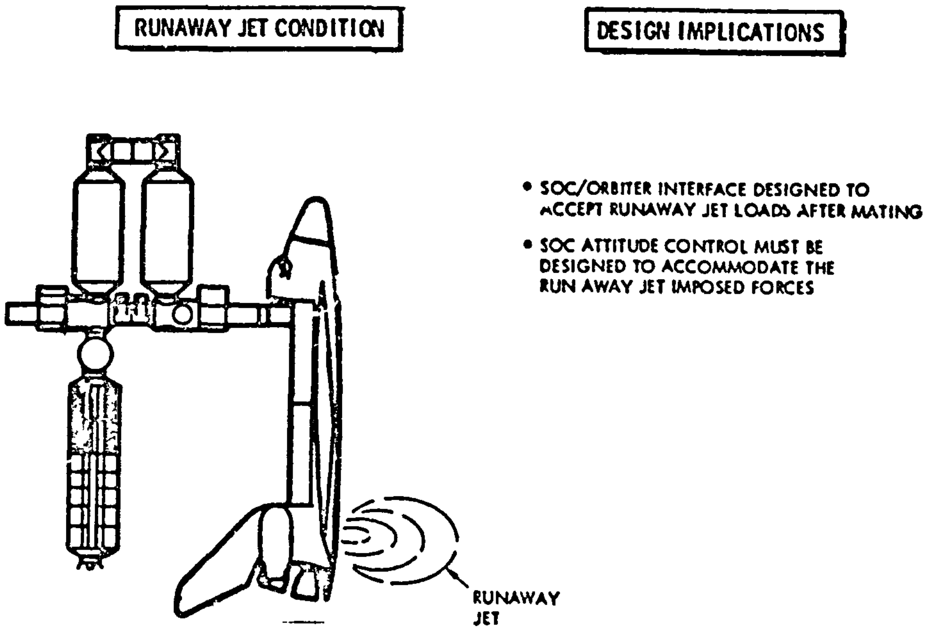

FIGURE 2.6 RUNAWAY JET CONTACT MODE

2.2 ORBITER PLUME EFFECTS

<u>The SOC Should Be Designed For The Plume Impingement Environment Associated With The "Hi-Z" Thrusting Mode</u>

If a runaway jet occurs at any time in the docking maneuver sequence up to the docking commit point (last few inches) the safest procedure will be to perform a "Hi-Z" abort maneuver. The "Hi-Z" thrusting mode minimizes the turnaround time and distance and precludes orbiter-SOC contact outside the safe docking envelope. Thus, although there is a very low probability of occurance for a runaway jet, particularly during the relatively short time interval (10 to 15 minutes) where the orbiter is relatively close to the SOC, it can happen, and the SOC design should be capable of tolerating the resulting plume environment (9 +Z thrusters and possibly pulsed firings of X and/or Y thrusters). Figures 2.7 and 2.8 indicate the plume pressure and plume heating rates respectively that will be experienced by the SOC and any vehicles attach to the SOC. Table 2.2 summarizes the forces, moments, heating rates, and particulate deposition on the various modules and SOC components that will occur during a Hi-Z abort maneuver.

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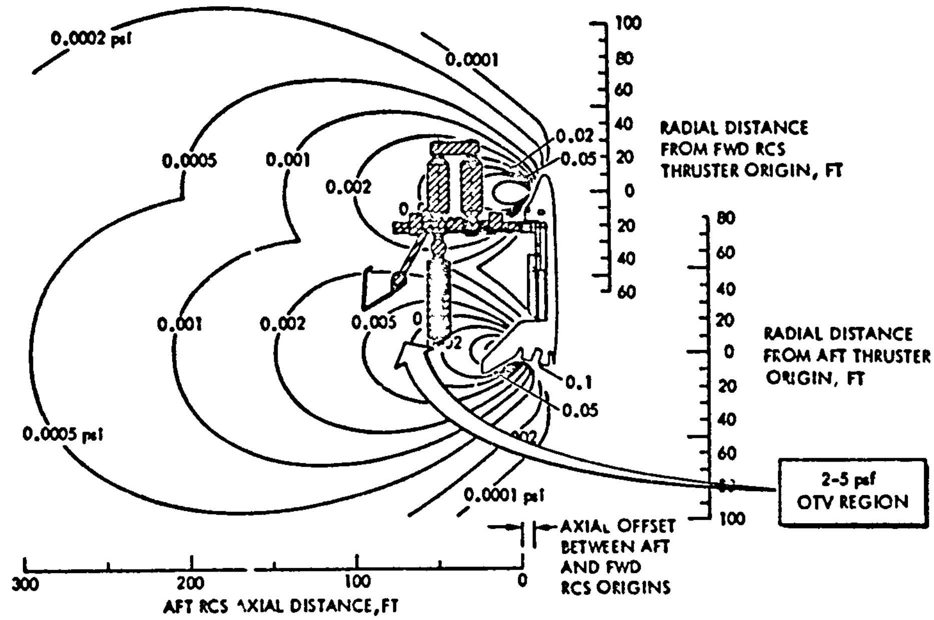

FIGURE 2.7 PLUME PRESSURE CONTOURS FOR 9 Z-THRUSTERS FIRING

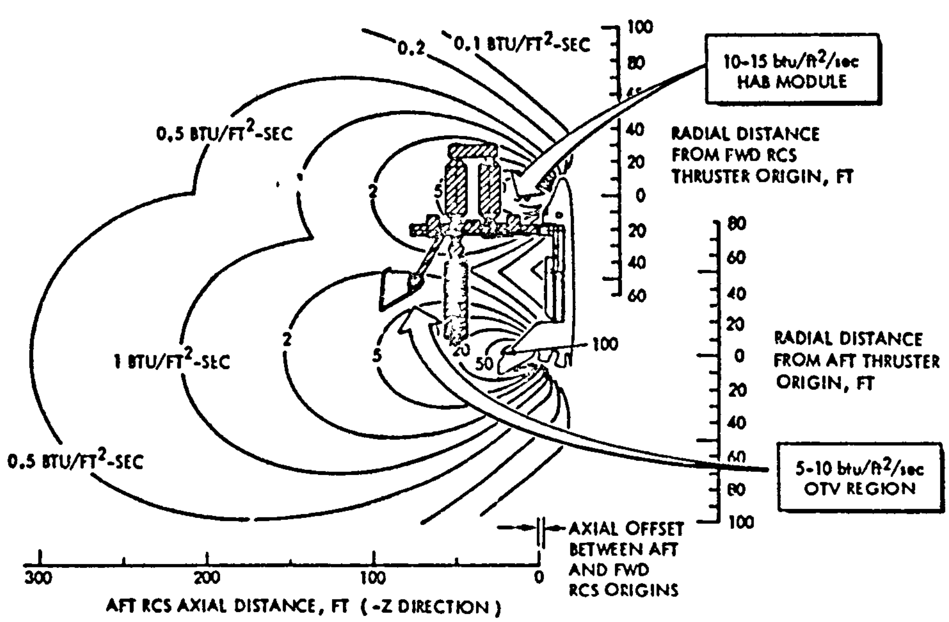

FIGURE 2.8 PLUME HEATING RATE CONTOURS FOR 9 Z-THRUSTERS FIRING

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TABLE 2.2 ORBITER RCS PLUME IMPINGEMENT RESULTS ON SOC

DESCRIPTION	MASS DEPOSITION RATE (lbm/sec)	SOC IMPINGEMENT FORCES (lbf)			SOC MOMENTS (lbf-ft)			CONVECTIVE HEATING RATE (Btu/sec)
		F_x	F_y	F_z	M_x	M_y	M_z	
FWD RCS, 3 ENGINES (+Z DIRECTION)								
HABITABILITY MODULE NO 1	3 146	981 1	0	41 8	0	24 058 1	0	7730 0
LOGISTICS MODULE	0 272	59 7	11 7	60 6	809 0	-508 2	659 0	637 7
SERVICE MODULE NO 1	0 266	41 2	0	29 0	0	-289 4	0	609 9
TOTAL	3 684	1082 0	-11 7	47 8	809 0	23,260 5	699 0	
AFT RCS, 6 ENGINES (+Z DIRECTION)								
PARKED PLANETARY VEHICLE	0 354	90 6	0	50 8	0	-5,185 7	0	773 2
SAM**	2 564	867 2	0	-70 2	0	-67 579 0	0	6540 6
R/CM MODULE	0 280	60 0	23 5	39 2	1758 7	-3,255 6	-747 9	569 8
TOTAL	3 198	1017 8	23 5	19 8	1758 7	-76,020 3	-747 9	
-Y THRUSTER, 1 ENGINE								
SOLAR ARRAY (= 52° ANGLE)	0 720	116 7	-171 4	-45 1	6018 4	-1957 3	19,554 1	1659 8
4 3 M ANTENNA (-Y DIRECTION)	0 036	3 2	-5 4	-0 4	123 2	55 2	220 6	45 9
RADIATORS (-Y DIRECTION)	0 009	2 1	-1 4	-0 5	35 1	20 3	79 0	20 6
TOTAL	0 765	122 2	-178 2	-46 0	6176 7	-1881 8	19,853 8	

*NOTES (1) ONE ENGINE PRODUCES 870 lb_f THRUST
(2) MASS FLOW RATE OF ONE ENGINE—3 01 lbm/sec
(3) MASS FLUX CONTAINS APPROX 9% CO_2, 17 5% CO and 29 2% H_2O

**ASSUMED THAT THE SAM WAS OPAQUE (INTERNAL PARTS STOWAGE)

RCS Plume Effects From Normal Docking Operations are Relatively Mild

The orbiter $+Z_B$ thrusters tend to receive little use during final closure operations for normal docking. Most thruster actions will be for corrections in orbiter X and Y body directions. Almost all close in thruster action for normal docking will be minimum impulse adjustments, approximately 80 milliseconds in duration. These brief bursts will be mostly single or dual thruster firings and will inherently be aimed away from the central SOC modules by the nature of the thruster geometry. What little impingement exists in these cases will be mostly from the very low flux region of the plume field. Thus, the main concern for normal docking is the cumulative effects of mass deposition on sensitive SOC surfaces. These mass deposites will buildup over the years with the many repeated dockings required. This condition is illustrated in Figure 2.9. A worst case solar array orientation is shown and the mass of contaminants impinging on the solar arrays is indicated. An estimate of the total mass of contaminants that could be deposited is shown as 1000 lbs for a 20 year period. These effects require further, detailed study.

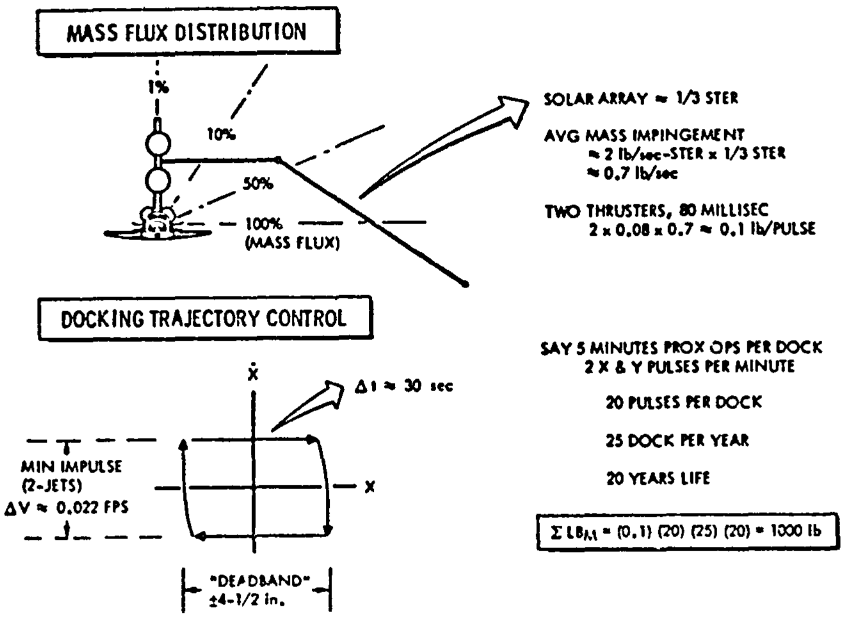

FIGURE 2.9 POTENTIAL FOR PLUME INDUCED CONTAMINATION

<u>Special SOC Provisions Are Probably Required For Protection From Hi-Z Abort Thrusting Plumes</u>

Although close in aborts during docking are a very low probability event, the combined effects of 9 Z-thrusters firing directly on the SOC for a period of two seconds or more can be severe. Large quantities of exhaust products can be quickly deposited on the frontal surfaces exposed to the plume. Large control disturbances can be induced by plume impingement forces. For the baseline SOC configuration pitching moments exceeding 75000 ft lb and yawing moments approaching 20,000 ft lb are possible. Shielding is probably required for OTVs parked on the flight support and servicing facility beneath the service modules. Figure 2.10 illustrates the induced forces effects to the SOC and also the implications to an OTV parked for servicing. Plume induced rippling and shearing forces on the delicate MLI thermal protection blankets can cause extensive damage. Thus, significant attention must be given in the SOC design for protection against these severe plume induced environments.

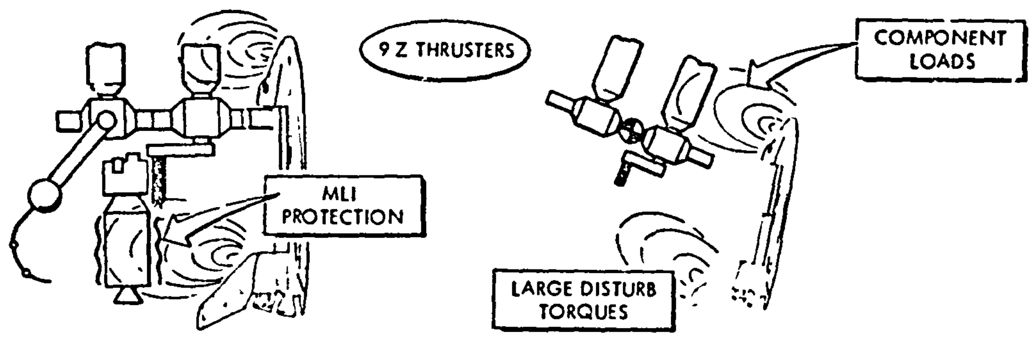

FIGURE 2.10 HI-Z ABORT THRUSTING PLUME EFFECTS

2.3 DOCKING INTEFACE CONCEPT

A Standard Mating Interface Can Be Provided

The principal output of the docking/berthing design concept was the development of a standardized mating interface that would accommodate the SOC module mating, the orbiter to SOC mating, and also be compatible with other programs requiring the mating of modules/pallets, and interfacing with the orbiter. A standard mechanical alignment and latching concept was developed as well as a standard utilities interface arrangement. The utilities arrangement dedicates specific areas for the various utilities crossing the interface, i.e., electrical power, data, air distribution, etc. The standard interface also provides a 1 meter clear opening which will accommodate crew transfer through the interface for either a suited crewman or a shirtsleeve crewman, Figure 2.11.

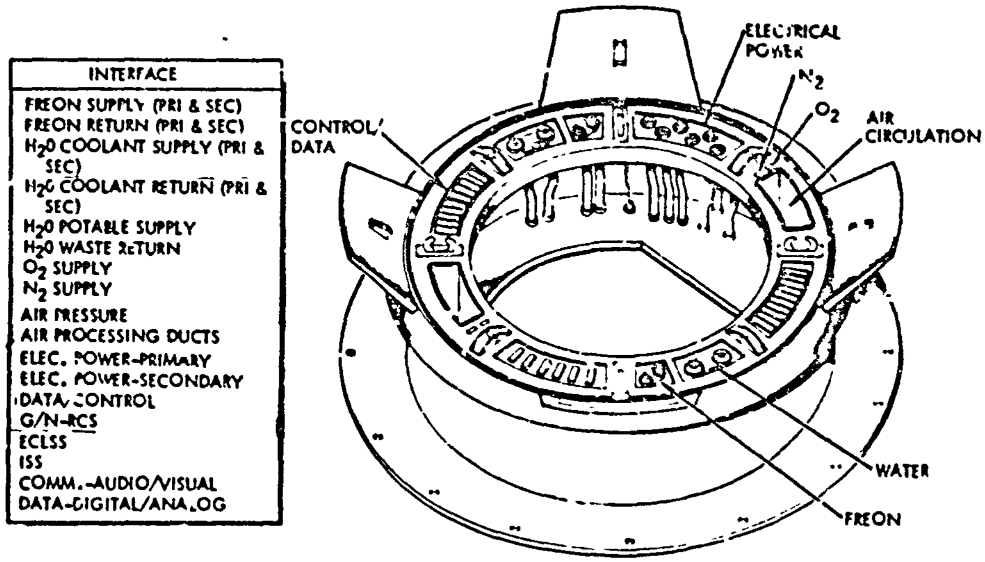

FIGURE 2.11 UTILITIES INTERFACES ARRANGEMENT

All of the utilities are remotely actuated in order to make the interface connections. These connections are made after the mechanical mating has been accomplished and verified. The remote actuation mechanism has a manual override capability. Sufficient volume is available to permit either a shirtsleeve or suited crewman to perform maintenance operations within the mated interface as illustrated in Figure 2.12.

The mechanical and alignment interface can either be an active element which will accommodate a docking maneuver with an active attenuation system, or be a passive element which will accommodate a berthing mate without active attenuation.

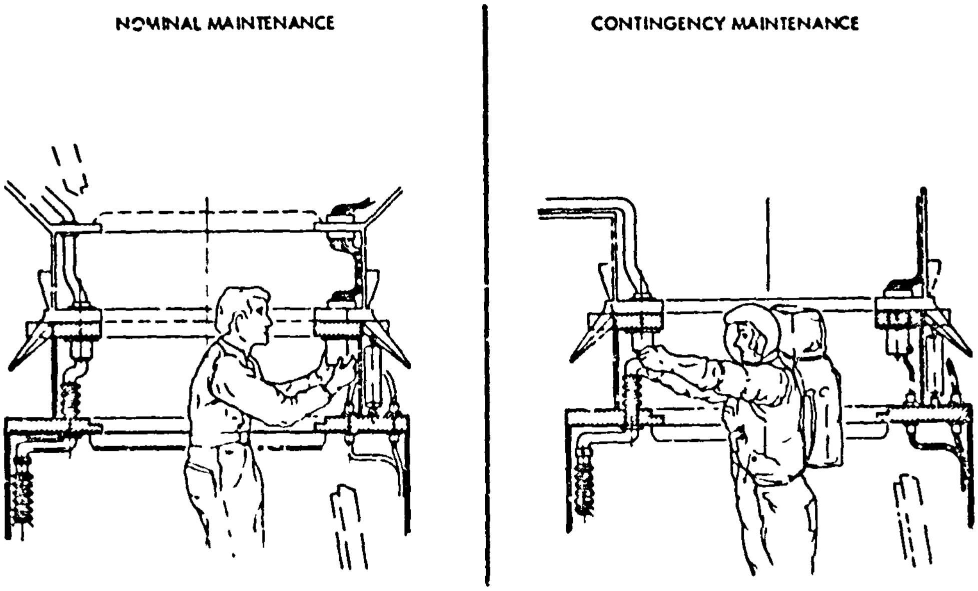

FIGURE 2.12 UTILITIES INTERFACE ACCESS

<u>A Docking Module Compatible With the Orbiter and Accommodating the Standard Mating Interface is Feasible</u>

A docking module concept was developed that incorporated the standard mating interface. The docking module provides a pressurized, shirtsleeve, transfer capability between the orbiter and the SOC or any other pressurized spacecraft. The standard utilities interface arrangement, developed for the SOC modules interface, provides the utilities across the docking module interface.

The docking module also interfaces with the existing space lab tunnel adapter, but is structurally supported independently by the payload bridge fitting structure and latches. Isolation of the docking loads from the tunnel adapter is accomplished with the use of a flexible seal member. The docking module has the capability to extend .38M (15") above the mold line of the orbiter and when retracted provides a .9M (36") clearance below the payload bay doors. This excursion permits docking clearance and EVA clearance for payload bay contingencies. A 1 meter clear opening is maintained throughout the module. The installation of the module within the orbiter is illustrated in Figure 2.13.

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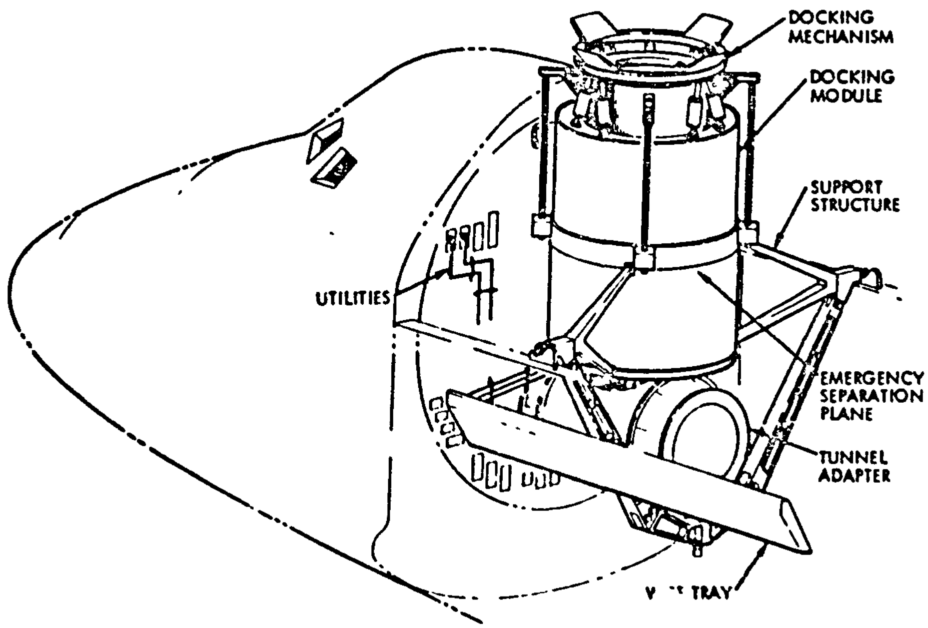

FIGURE 2.13 DOCKING MODULE CONCEPT

<u>Docking Module is not Required to be an Airlock, But can be Provided if Growth Applications Warrant</u>

By utilizing the standard orbiter crew cabin arrangement, which includes an airlock inside the cabin, no additional airlock capabilities are required. Any EVA activities can be accomplished through the onboard airlock. However, if, for instance, a space lab requires the capability for EVA while retaining shirtsleeve passage between the crew cabin and the space lab, the docking module can become an airlock. The installation of a hatch in the upper end of the docking module is the principal change that would be necessary in order to provide the airlock capability. Figure 2.14 illustrates four mission arrangements and their relationship to EVA activities. The figure also indicates the feasibility of removing the orbiter airlock from inside the crew cabin if the docking module is utilized as an airlock.

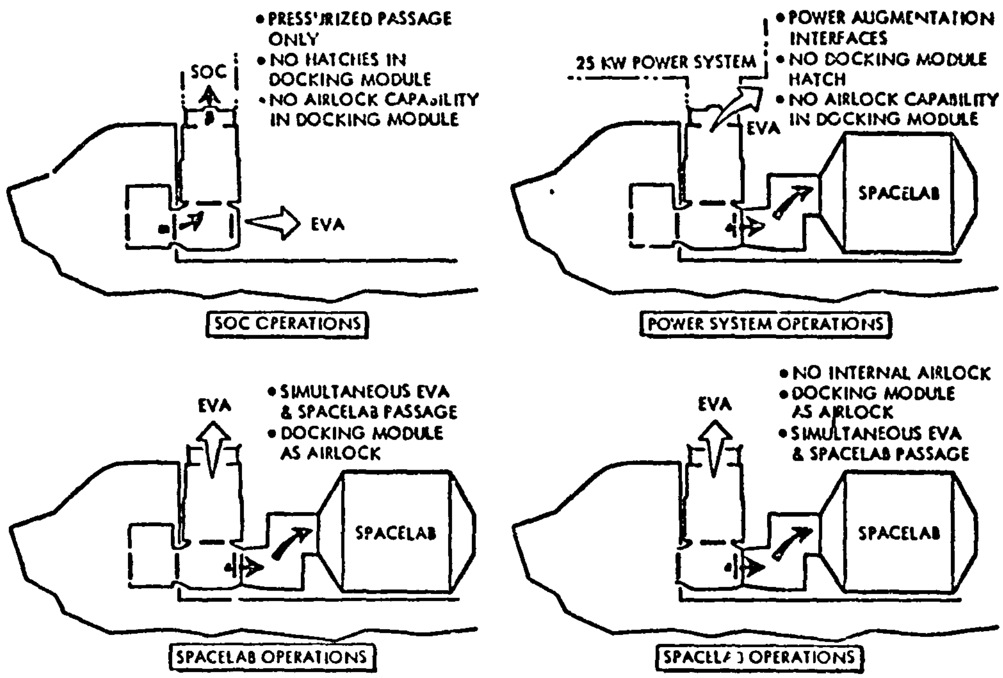

FIGURE 2.14 EVA OPTIONS

Docking Module Acceptance for Unmanned Systems

Even though the docking module is designed for pressurized activities, it is capable of being mated to unmanned, unpressurized spacecraft. The utilities connections across the interface are still applicable and will permit EVA maintenance if required.

EVA passage through the docking module, however, requires that the mating spacecraft provide clearance for a suited EVA crewman to exit the docking module, Figure 2.15.

The docking mechanism, that portion that contains the guidance, latching, attenuation, and utilities interfaces, can be mounted to other docking or berthing devices that may be more amenable to unmanned activities, Figure 2.16.

In summary, a standard mating interface was developed that will accommodate the mating of SOC modules, can be used to mate the orbiter to the SOC through a pressurized docking module, and can be utilized in unmanned or unpressurized spacecraft mating.

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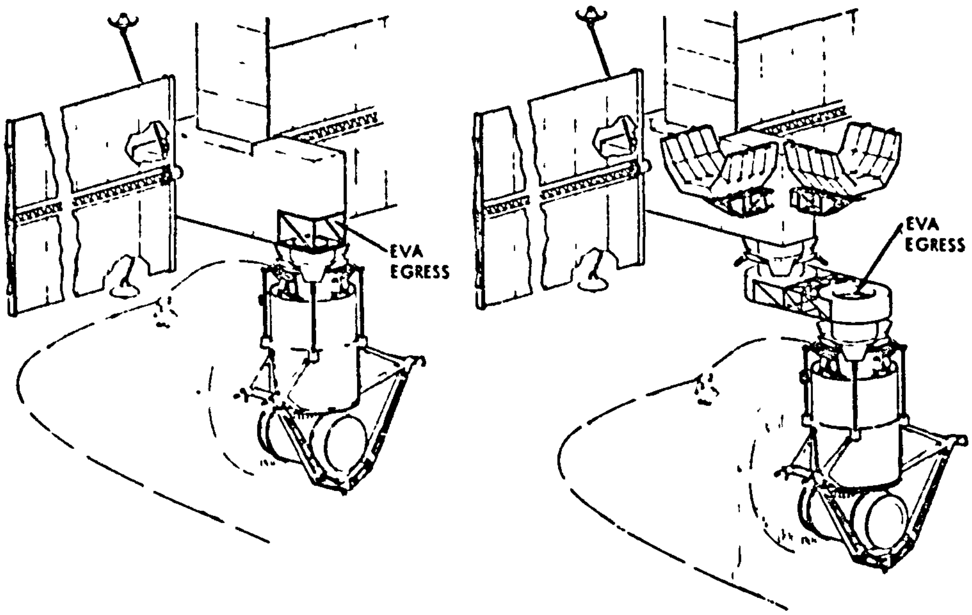
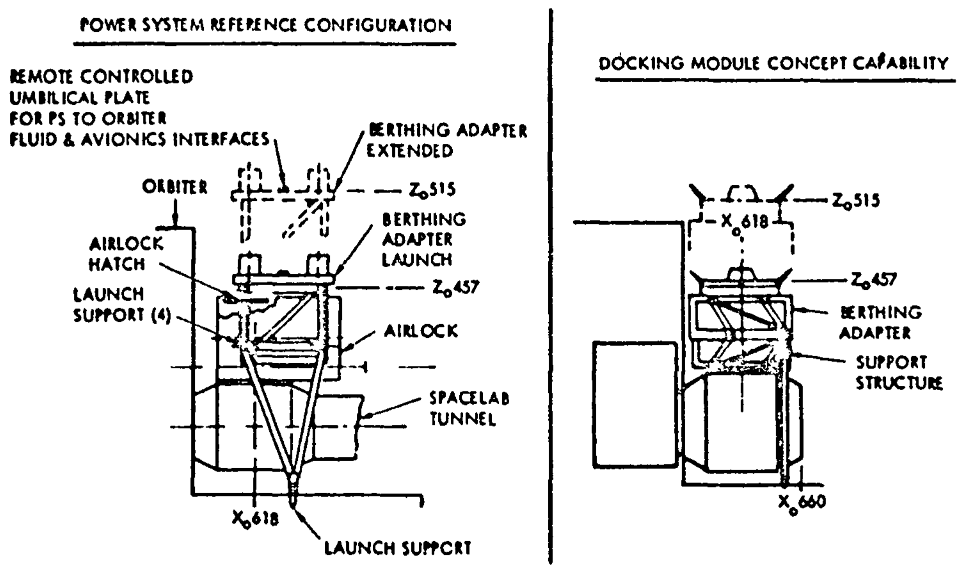


FIGURE 2.15 EVA DESIGN IMPLICATIONS FOR UNMANNED SYSTEMS



F FIGURE 2.16 DOCKING SYSTEM FOR UNMANNED OPERATIONS

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2.4 BERTHING OPERATIONS

RMS Berthing Requires Software Mods, But Appears Feasible

High fidelity simulation runs by SPAR have shown the RMS has the basic capability to handle the large masses and inertias associated with orbiter/SOC berthing operations. However, minor changes will be required in the control software to permit stable control of the arm with these large system masses. Figure 2.17 illustrates the geometry of the SOC and of the Orbiter that was established to perform the berthing simulations.

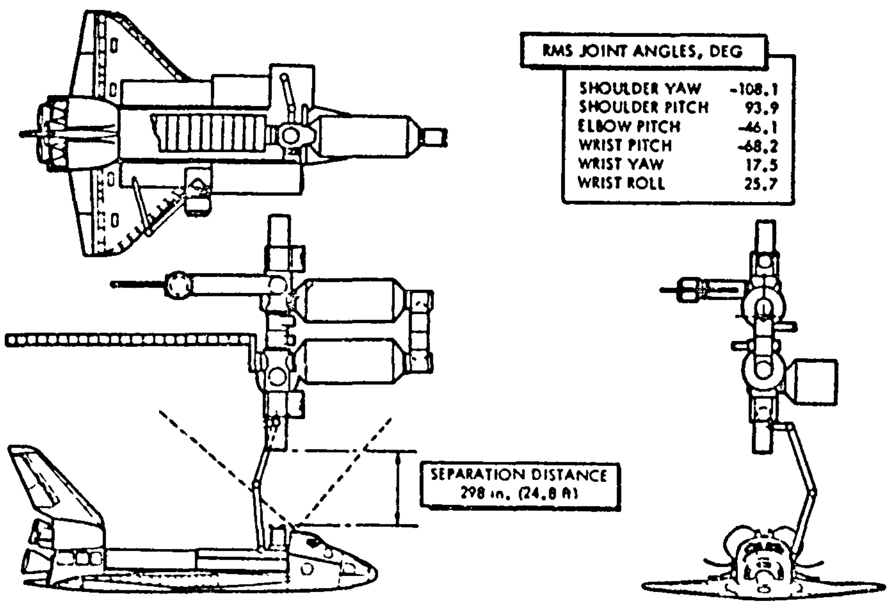

FIGURE 2.17 ORBITER/SOC BERTHING GEOMETRY

Residual motions between the orbiter and the SOC were successfully arrested using a slightly modified manual augmented mode. This mode eliminates the automatic switchover to the joint position hold mode when joint rates are reduced to threshold limits built into the software. Use of normal arm stopping modes which include the automatic switchover feature resulted in undamped oscillations. Since all of the RMS control modes for moving payloads have the builtin switchover feature, it is not possible, therefore, to reposition the orbiter to the SOC berthing port with the present software. Undamped oscillations would result. However, the same modified manual augmented mode of operation used in the stopping action above produced stable control, thereby permitting the use of the arm for maneuvering the orbiter to the SOC berthing port. Plots of the relative oscillations resulting from three of the simulation runs are shown in Figure 2.18. The undamped oscillations are shown in run #1, while run #3 shows the results of modifying the manual augmented mode which damps the oscillations within 400-600 sec. Run #6 was concerned with repositioning the orbiter from the motion arrest location to the mated position at the SOC interface. The modified operator commanded automatic sequence mode was used to perform this reposition operation. As indicated, an unstable condition was observed after approximately 500 sec. Utilizing the modified manual augmented mode for the reposition maneuver, however, was suitable. Table 2.3 summarizes the seven simulation run results. Thus, it is felt that the RMS fundamentally has the capability for berthing the orbiter to the SOC, but minor software mods are required for stable control. Additional simulation analyses are required to confirm this finding with the addition of SOC/Orbiter body flexibility effects which were not simulated in the current analysis.

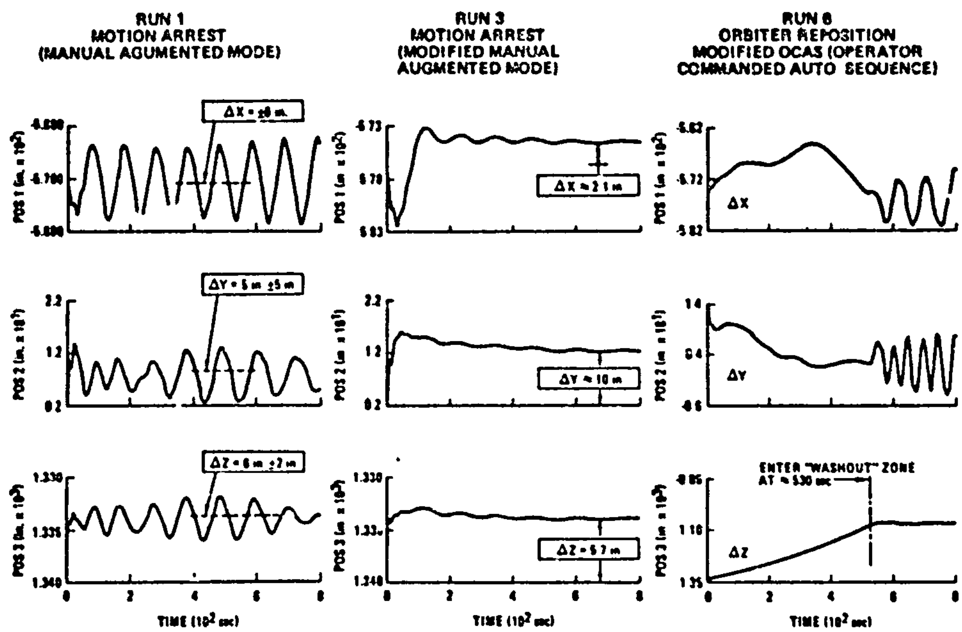

FIGURE 2.18 BERTHING SIMULATION RESULTS RELATIVE CG POSITION

TABLE 2.3 RMS BERTHING RESULTS SUMMARY

RUN	CASE CONDITIONS	SUMMARY RESULTS
1	• ARREST INITIAL MOTION (1 ft/sec .025°/sec) MOTION IN THE ARM PLANE • MAM/CONTROLLERS IN NEUTRAL (I.E., ZERO RATE COMMANDS)	• PHM AUTOMATICALLY ENGAGED FEW SECONDS AFTER "RIGIDIZATION" • MARGINAL STABILITY – NO APPRECIABLE DAMPING (800 sec) – SOC CENTER OF MASS PEAK TO PEAK EXCURSIONS 1.5 ft
2	• SAME AS ABOVE WITH INITIAL MOTION PERPENDICULAR TO THE ARM PLANE	• UNDAMPED OSCILLATION
3	• ARREST INITIAL MOTION (1 ft/sec, .025°/sec) MOTION IN THE ARM PLANE • MODIFIED MAM/CONTROLLERS IN NEUTRAL	• STABLE CONTROL EXHIBITED AFTER 400 SECONDS – SOC CENTER OF MASS PEAK TO-PEAK EXCURSION WITHIN 1 INCH – SOC ATTITUDE EXCURSION WITHIN 0.2 DEG • RELATIVELY HIGH LOADS FOR SHORT PERIOD IMMEDIATELY AFTER RIGIDIZATION, LEVELS ACCEPTABLE
4	• SAME AS ABOVE WITH SOC INERTIA 10^7 HIGHER THAN BASELINE, SIMULATE "STOPPING PHASE" WITH SOC ACS ACTIVE	• HIGHER FREQUENCIES ARE EXHIBITED AND SLIGHTLY HIGHER LOADS, BUT STILL WITHIN ACCEPTABLE LEVELS
5	• MANEUVER SOC WITH MODIFIED MAM • INITIAL CONDITIONS FROM END OF RUN 3 • COMMAND TOWARDS "PREBERTH" POSITION/ORIENTATION	• SUITABLE STRATEGY FOR MANEUVERING THE SOC
6	• USING SLIGHTLY MODIFIED OCAS MODE – MANEUVER THE SOC TO "PREBERTH" POSITION/ ORIENTATION – STABILIZE THE SOC AT "PREBERTH" • INITIAL CONDITION FROM END OF RUN 3	• OCAS QUITE SUITABLE FOR MANEUVERING THE SOC • OCAS NOT SUITABLE FOR STABILIZING THE SOC, MARGINAL STABILITY IS EXHIBITED NEAR THE "PREBERTH" POSITION
7	• ARREST HIGH ANGULAR MOTION (.052 ft/sec, .1732°/sec) • MODIFIED MAM/CONTROLLERS IN NEUTRAL	• MODIFIED MAM CONFIRMED AS THE STRATEGY FOR STOPPING AND/OR STABILIZING THE SOC

3.0 SOC ASSEMBLY

The SOC assembly procedure is premised on the reference configuration depicted in Figure 3.1 and the use of the Shuttle Orbiter as an assembly base. In that capacity, the role of the orbiter, the requirements imposed on it, and the equipment needed to perform the assembly operations must be determined. In this section of the report, these issues are examined in conjunction with several assembly scenarios. In addition, visibility, lighting and CCTV provisions and the requirements to stabilize the untended SOC during partial assembly configurations are presented.

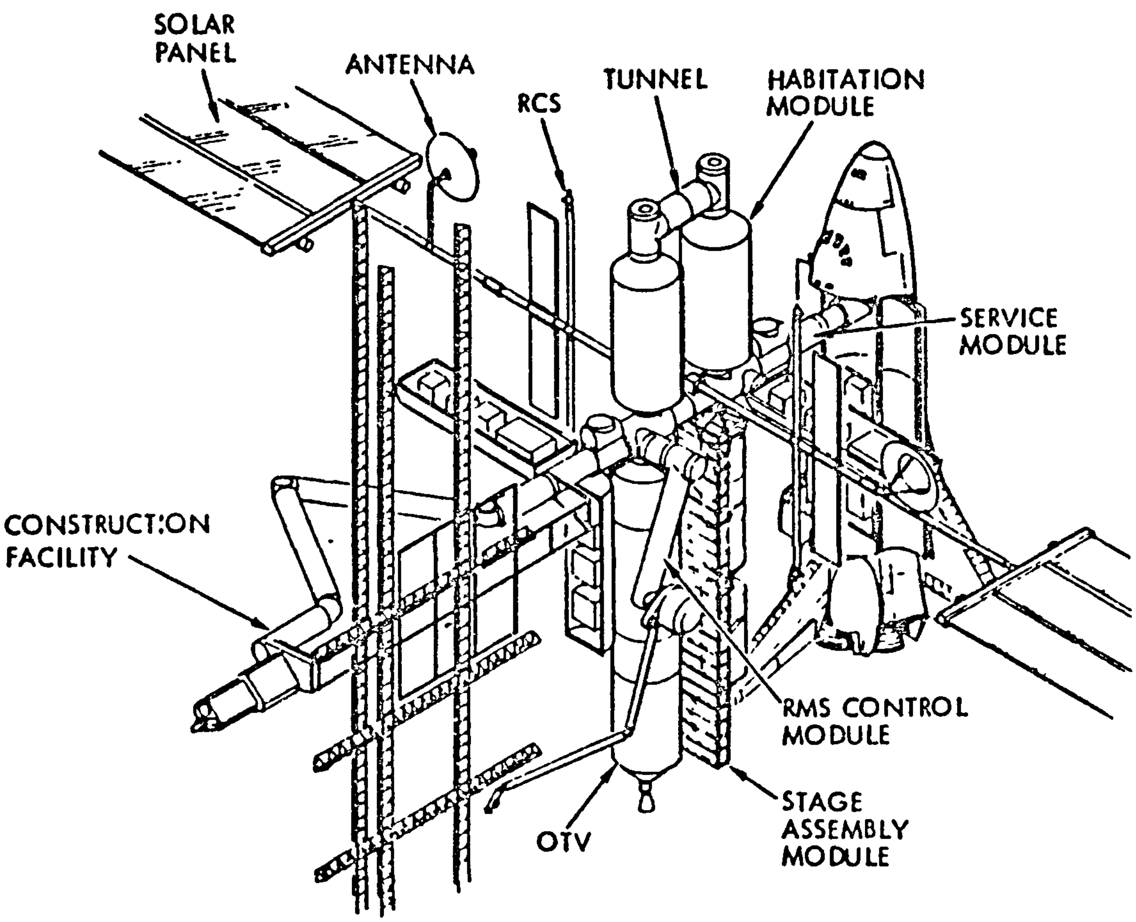

FIGURE 3.1 SOC REFERENCE CONFIGURATION

3.1 SUMMARY

The SOC Can and Should Be Designed to Accommodate Variations in the Build Plan

Future uncertainties lead to the need for versatility in the SOC design. The exact nature, timing and rate of growth of user program requirements are difficult to predict. There are also uncertainties in funding availability. Program funding is subject to other national priorities and can vary with general economic trends. Further, international space developments may introduce new urgencies and/or changes to near term program emphasis. Thus, the SOC design concept should allow for variations in the buildup scenario to meet these evolving future needs and influences.

Preliminary analyses have shown that modest changes to the baseline SOC configuration can satisfy a wide range of build plans. For example, the baseline RCS system is not adequate for full functional capability with just one service module. A small supplemental RCS system will satisfy the control needs for the direct buildup scenario, but would be seriously limited for most evolutionary build plans. However, changing the design to allow installation of the complete baseline "dual boom" RCS system on the first service module (instead of half a system on each service module) would satisfy the RCS control functions and redundancy needs for virtually all buildup options.

Also, momentum control concepts sized to the full up SOC configuration can meet the needs of all early mission options. Even assuming one-half of the momentum control is located in each service module there is enough capacity to perform many early missions with configurations centered on the use of a single service module.

SOC Assembly Variations

The use of the Shuttle Orbiter as a base for space construction has been thoroughly studied by many industry and NASA investigations. The thrusts of most of these studies dealt with construction of space platforms from basic building block structural elements. Very little emphasis was placed on assembling large modules together as in the SOC. Nevertheless, there were indications that the orbiter and its support equipment can accomplish the task. To investigate the feasibility of such an approach, a logical SOC assembly sequence was determined. Initially, a baseline assembly scenario was generated in accordance with guidelines of a NASA-generated buildup sequence. Subsequently, two variations to the baseline were investigated in which the delivery of the RMS Control Module was manipulated to assess its sensitivity to the overall construction of the SOC. Furthermore, two evolutionary SOC assembly scenarios were examined that provide a high degree of mission flexibility. The desirability of an evolutionary approach would be further enhanced by a build sequence that permits the earliest operational capability and, at the same time, minimizes front end costs.

In generating the scenarios, a number of operational issues were considered for assembling the SOC. Table 3.1 lists the issues along with the various considerations that were specifically addressed in relation to the issues. Two of these issues, alignment aids and stabilization of the untended SOC assembly, were found to be extremely significant and were treated separately. As a further aid in formulating the scenarios, 1/48 scale models of the orbiter and the various SOC modules were utilized to simulate the buildup sequences. The fidelity of the models was sufficient to establish the feasibility of the selected SOC-orbiter orientations and to determine gross reach capabilities of the manipulators utilized in the assembly. A photographic array of the 1/48 scale models is shown in Figure 3.2 in which a variation to the baseline sequence is illustrated.

A significant result of the SOC assembly task was the identification of two major pieces of assembly equipment which facilitate the SOC assembly. These pieces of equipment, the Payload Installation and Development Aid (PIDA), and the Handling and Positioning Aid (HPA) are in addition to those considered standard equipment aboard the orbiter and the SOC. The PIDA, Reference 1, is intended to move large payloads through a prescribed and controlled path between the confined quarters of the payload bay and a position outside the critical maneuvering area of the orbiter. As utilized in the SOC assembly, two synchronized drive PIDA arms deploy a SOC module out of the payload bay in a two-stage movement as illustrated in Figure 3.3. Each PIDA arm consists of a deploy/stow mechanism, a payload interface mechanism, an electromechanical rotary actuator with its respective electronic controls, and a base, with a jettison interface, that connects the assembly to the orbiter longeron bridge fitting as shown in Figure 3.4.

The HPA is mainly an attachment device to which various payloads can be berthed and which provides a multi-positioning/orientation capability of the various payloads for orbiter-based construction and near-orbiter satellite servicing activities. In that capacity, it complements the role of the RMS by maximizing its reach and enhancing its capability to access points on payloads of complex geometric configurations that otherwise would be inaccessable to the RMS as illustrated in Figure 3.5. The HPA also provides improved visibility of the particular work site to the RMS operator or brings the work site within the direct line of sight of a CCTV camera. Conceptually, the HPA is envisioned as a relatively stiff arm with five degrees of freedom. It will consist of an orbiter interface mechanism, a tubular shaped drive arm and a payload interface mechanism with its own electronic control as seen in Figure 3.6.

TABLE 3.1 SOC ASSEMBLY OPERATIONAL ISSUES

ISSUE	CONSIDERATION
ORIENTATION OF STOWED SOC MODULE	• COMPATIBLE FOR DEPLOYMENT WITH PIDA • COMPATIBLE FOR GRASPING WITH RMS • COMPATIBLE WITH FINAL ASSEMBLED POSITION
BERTHING PORT SELECTION	• COMPATIBLE WITH RMS REACH • VISIBILITY—LIGHTING
TRANSLATION PATH	• COMPATIBLE WITH RMS ARTICULATION CAPABILITY • CLEAR ORBITER APPENDAGES • CLEAR SOC APPENDAGES
ALIGNMENT AIDS	• MINIMAL IMPACT ON SOC MODULES • SIMPLE AND RELIABLE CONCEPT • VISIBILITY—DIRECT OR CCTV—LIGHTING
CHECKOUT	• PREDEPLOYMENT CHECKOUT OPERATIONS • POST-DEPLOYMENT CHECKOUT OPERATIONS
STABILITY OF UNTENDED SOC	• SOC PARTIAL ASSEMBLIES • AUXILIARY SYSTEMS

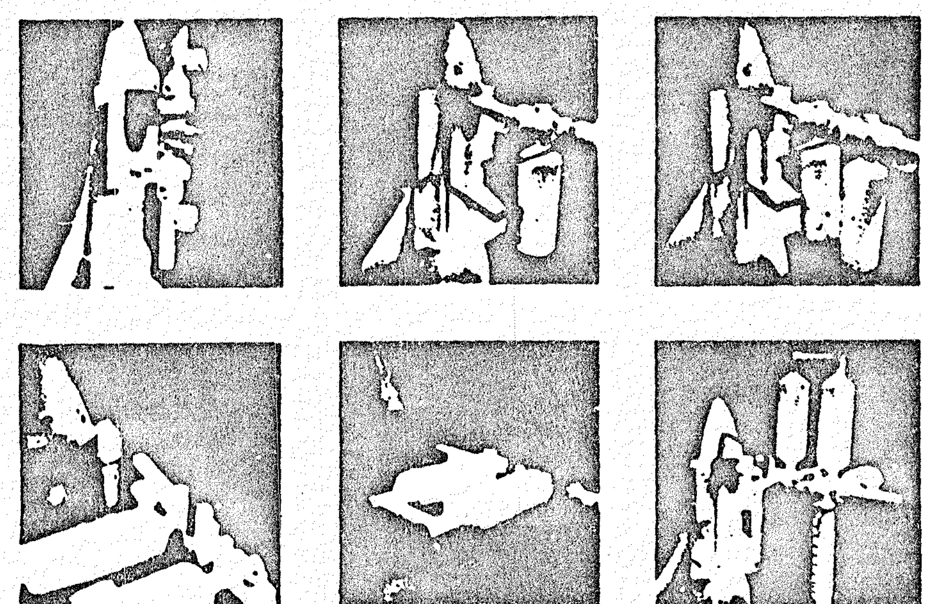

FIGURE 3.2 BUILDUP EVALUATION TECHNIQUE

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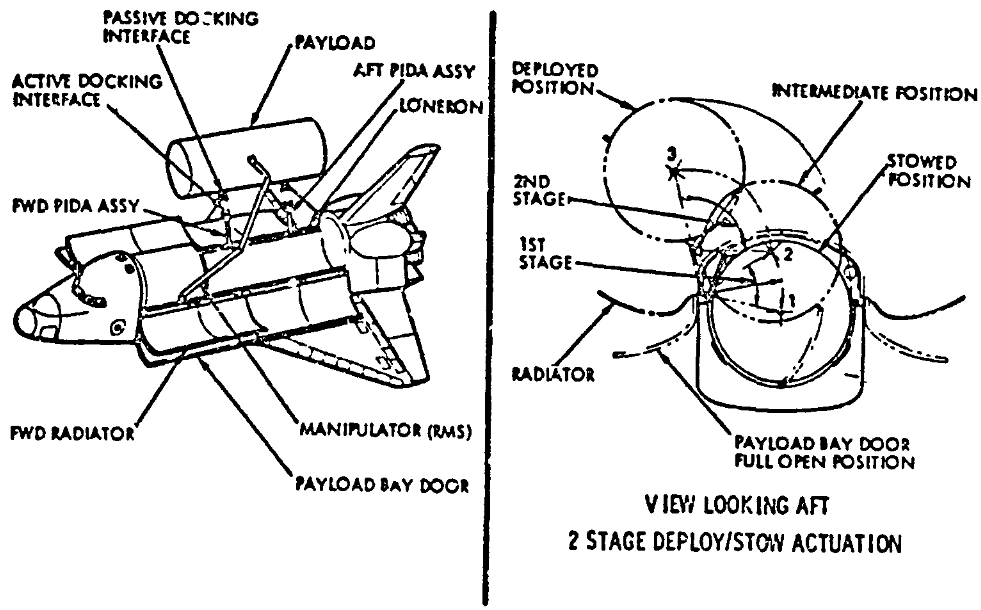

FIGURE 3.3 PIDA OPERATION

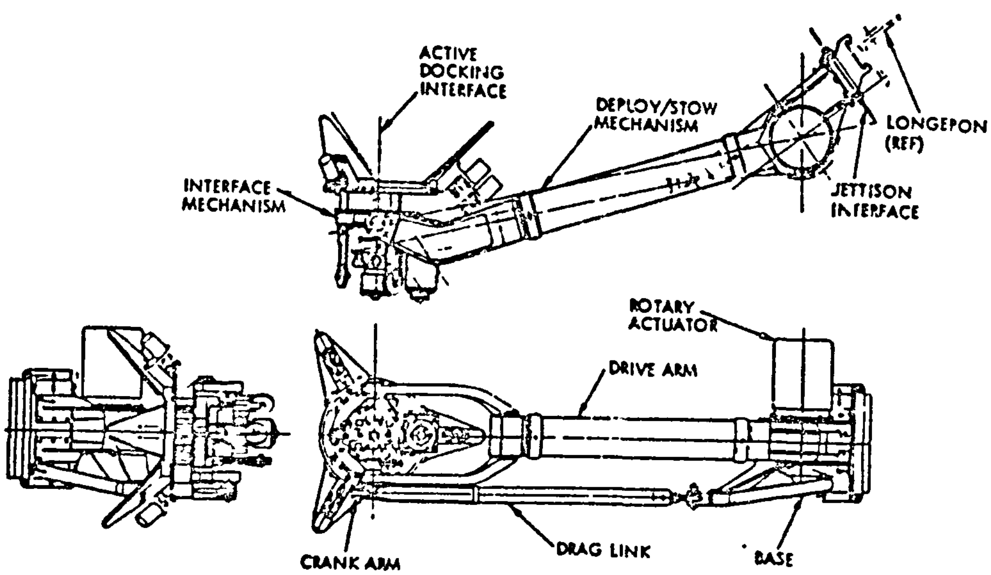

FIGURE 3.4 PIDA ASSEMBLY

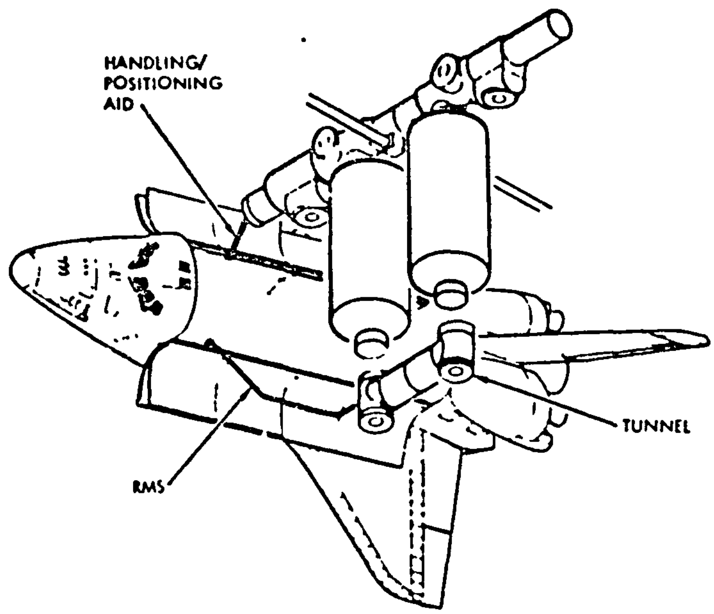

FIGURE 3.5 EXAMPLE OF SOC ASSEMBLY OPERATION USING HPA

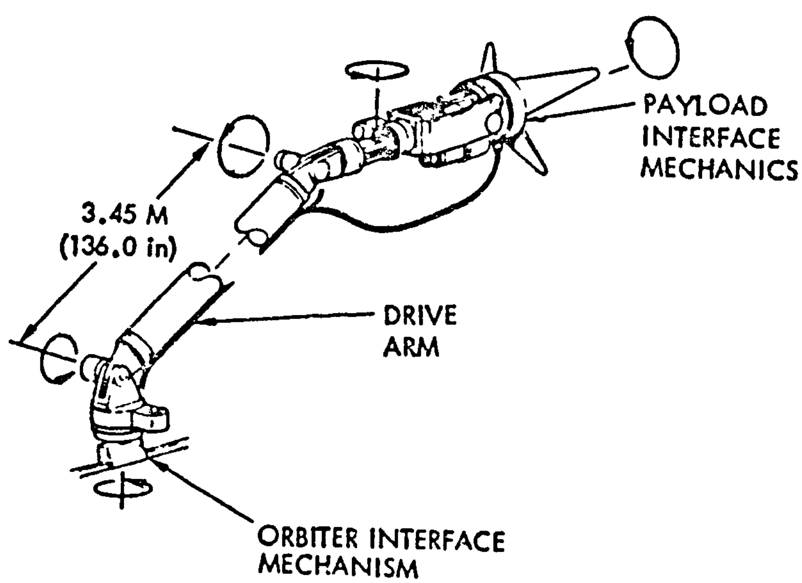

FIGURE 3.6 HANDLING AND POSITIONING AID CONCEPT

SOC Assembly - Baseline Scenario

The baseline scenario utilized the NASA-generated buildup sequence where the SOC modules are produced and delivered to acheive "full-up' operational capability in the earliest feasible time period. A detailed analysis of this sequence was conducted which identified all required berthing/docking operations, examined translation paths, reach distances and visibility conditions. To fully assemble the SOC by the baseline scenario, seven orbiter flights are required to transport all of the SOC modules. The payloads for each of the seven flights and sequence of their assembly are listed in Table 3.2 and illustrated in Figure 3.7. A distinguishing feature of the baseline scenario is the use of the RMS Control Module (RCM) as an assembly tool in Flights 5B and 6A. All other assembly operations use the RMS. However, the reach of the RMS was found inadequate to attach the Tunnel Module (TM) to the SOC in Flight 6A and the task was assigned to the RCM with its adequate reach capability.

SOC Assembly - Alternative Scenario No. 1

An important feature of the SOC design is that it will provide dual access to and permit shirtsleeve transfer between all pressurized habitability modules. One of the elements in this important feature is the TM. It must be assembled to the SOC before it can be declared habitable. Concequently, the sooner the TM is attached to the SOC, the sooner it can be declared operational. In Alternate Scenario No. 1 the sensitivity of the SOC assembly sequence to an earlier attachment of the TM was investigated. Compared to the baseline scenario, Alternative Scenario No. 1, advanced the assembly of the TM and LM to Flight 5 rather than Flight 6. By this sequence, the SOC can be declared operational after Flight 5, i.e., without awaiting the launch and assembly of the RCM and the SAM. However, without the RCM, the available assembly tools are not adequate to attach the TM. Consequently, the handling and positioning aid (HPA) was used to assist in that assembly operation. The entire assembly sequence is shown in Table 3.3 and Figure 3.8. The use of the HPA is illustrated in Flights 5A, 5B and 5C.

SOC Assembly - Alternative Scenario No. 2

One of the noted options in the assembly of SOC was to advance the attachment of the RCM to the earliest flight possible in order to utilize its capability in a major assembly role. Alternative Scenario No. 2 presents such an option where the RCM was assigned to Flight No. 3. Consequently, its arm can be utilized for the attachment of HM-1 and HM-2. The sequence of Alternative Scenario No. 2 is listed in Table 3.4 and illustrated in Figure 3.9.

TABLE 3.2 SOC ASSEMBLY - BASELINE SCENARIO BUILDUP SEQUENCE

MODULE		CONFIGURATION 1	2	3	4	5	6	7
SERVICE MODULE 1	(SM-1)	X	X	X	X	X	X	X
SERVICE MODULE 2	(SM-2)		X	X	X	X	X	X
HABITATION MODULE 1	(HM-1)			X	X	X	X	X
HABITATION MODULE 2	(HM-2)				X	X	X	X
STAGE ASSEMBLY	(SAM)					X	X	X
RMS/CONTROL	(R/CM)					X	X	X
TUNNEL	(TM)						X	X
LOGISTICS MODULE	(LM)						X	X
CONSTRUCTION FACILITY	(CF)							X

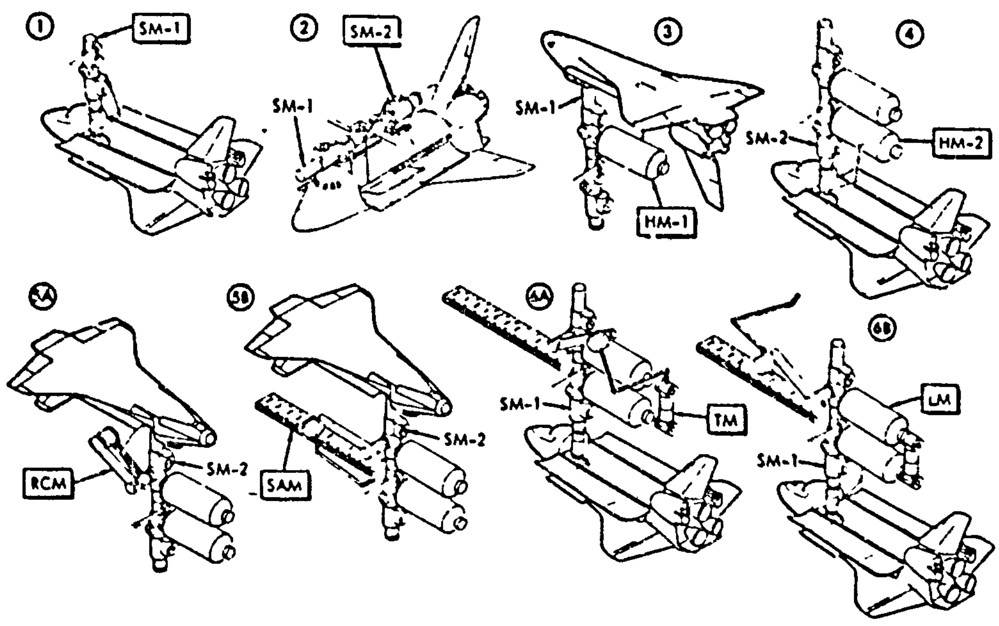

FIGURE 3.7 SOC ASSEMBLY - BASELINE SCENARIO

TABLE 3.3 SOC ASSEMBLY - ALTERNATIVE SCENARIO 1 BUILDUP SEQUENCE

MODULE		CONFIGURATION						
		1	2	3	4	5	6	7
SERVICE MODULE 1	(SM-1)	X	X	X	X	X	X	X
SERVICE MODULE 2	(SM-2)		X	X	X	X	X	X
HABITATION MODULE 1	(HM-1)			X	X	X	X	X
HABITATION MODULE 2	(HM-2)				X	X	X	X
LOGISTICS MODULE	(LM)					X	X	X
TUNNEL	(TM)					X	X	X
STAGE ASSEMBLY	(SAM)						X	X
RMS/CONTROL	(R/CM)						X	X
CONSTRUCTION FACILITY	(CF)							X

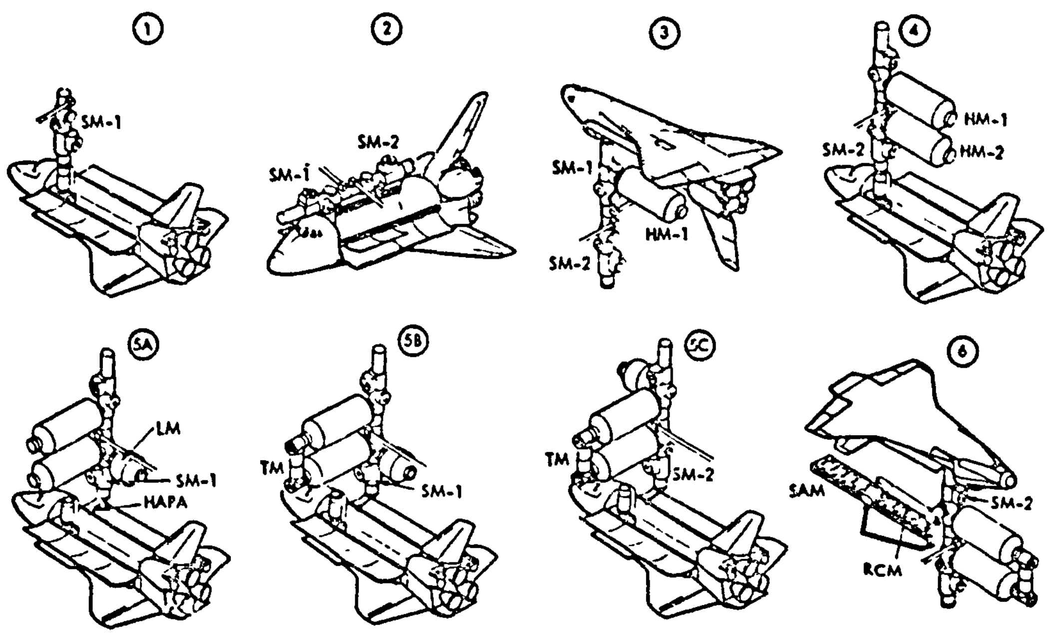

FIGURE 3.8 SOC ASSEMBLY - ALTERNATIVE SCENARIO 1

TABLE 3.4 SOC ASSEMBLY - ALTERNATIVE SCENARIO 2 BUILDUP SEQUENCE

MODULE		CONFIGURATION						
		1	2	3	4	5	6	7
SERVICE MODULE 1	(SM-1)	X	X	X	X	X	X	X
SERVICE MODULE 2	(SM-2)		X	X	X	X	X	X
STAGE ASSEMBLY	(SAM)			X	X	X	X	X
RMS/CONTROL	(R/CM)			X	X	X	X	X
HABITATION MODULE 2	(HM-2)				X	X	X	X
HABITATION MODULE 1	(HM-1)					X	X	X
TUNNEL	(TM)						X	X
LOGISTICS MODULE	(LM)						X	X
CONSTRUCTION FACILITY	(CF)							X

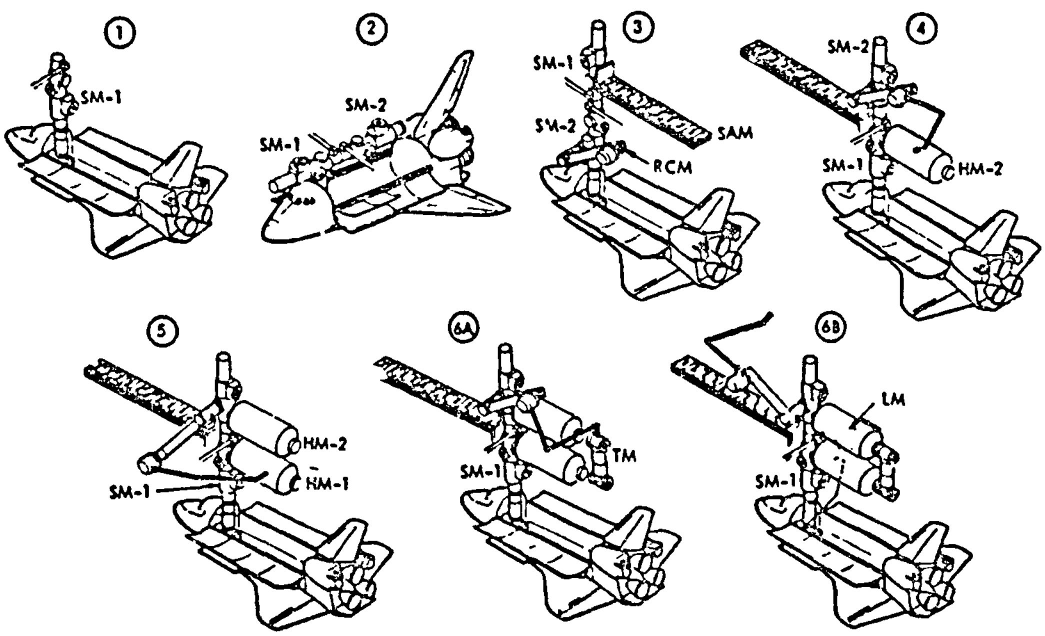

FIGURE 3.9 SOC ASSEMBLY - ALTERNATIVE SCENARIO 2

Evolutionary Buildup Concepts

The development of the assembly procedures discussed previously was premised on the acquisition of a fullup SOC as soon as possible. Alternative Scenario No. 1 offered an operational capability at the end of Flight No. 5 rather than Flight No. 6 as was the case for the baseline scenario and Alternative Scenario No. 2. These options are non-evolutionary. To develop the following two evolutionary assembly concepts, design features were added to the SOC to provide a high degree of mission flexibility. The desirability of such an approach would be further enhanced by a buildup sequence that permits the earliest operational capability and minimizes SOC front end costs. Toward that end, Evolutionary Scenarios 1 and 2 are presented.

SOC Assembly - Evolutionary Scenario No. 1

The duration of ERNO Spacelab missions are presently limited to the orbital duration of the orbiter. To extend those missions, more power and a larger habitat capacity than those provided by the orbiter are desirable. As can be seen in the buildup sequence listed in Table 3.5 and illustrated in Figure 3.10, Evolutionary 1 concept can provide that extended mission capability as a Shuttle-tended base with one service module (SM-1) and one habitation module (HM-1). The addition of a mission module (MM), HM-2, TM and LM can provide a permanent manned base for scientific research. The third phase of this evolutionary approach adds SM-2, SAM, RCM, and the construction facility for a fully assembled SOC. The MM is an addition to the presently planned SOC modules. It is conceived as a special module or as a Spacelab with an adapter to accommodate the geometry of SOC.

SOC Assembly - Evolutionary Scenario No. 2

In generating the buildup sequence of Evolutionary Scenario No. 1, all missions were assumed to be manned. In comparison, the buildup sequence of the Evolutionary Scenario No. 2 provides the added flexibility of employing SM-1 and the MM as an unmanned LEO platform by exchanging Flights 2 and 3 of evolutionary Scenario No. 1. That is, the MM will be the payload in Flight 2 and the HM-1 will be the payload in Flight 3. If the MM is assumed to be a Spacelab, the SM-1 will function as a surrogate orbiter payload bay which provides the necessary services to the Spacelab. With a revisit capability, the unmanned LEO platform will be the prelude to a fullup SOC. The buildup sequence of Evolutionary Scenario No. 2 is listed in Table 3.6 and illustrated in Figure 3.11.

SOC Assembly Conclusions

In investigating the indicating SOC assembly scenarios, the major impacts on the orbiter and SOC designs become apparent. In addition to the standard RMS and the payload bay lights, the orbiter must provide the PIDA and HPA. These pieces of construction equipment along with few delta provisions on the SOC can accommodate all possible buildup scenarios. For the SM, an interim attitude stabilization capability is required for safe

TABLE 3.5 SOC ASSEMBLY - EVOLUTIONARY SCENARIO 1 BUILDUP SEQUENCE

EVOLUTION			MODULE	CONFIGURATION 1	2	3	4	5	6	7	8
FULLY ASSEMBLED SOC	PERMANENT MANNED BASE	SHUTTLE TENDED BASE	SM-1	X	X	X	X	X	X	X	X
			HM-1		X	X	X	X	X	X	X
			MM			X	X	X	X	X	X
			HM-2				X	X	X	X	X
			TM					X	X	X	X
			LM					X	X	X	X
			SM-2						X	X	X
			SAM							X	X
			R/CM							X	X
			CF								X

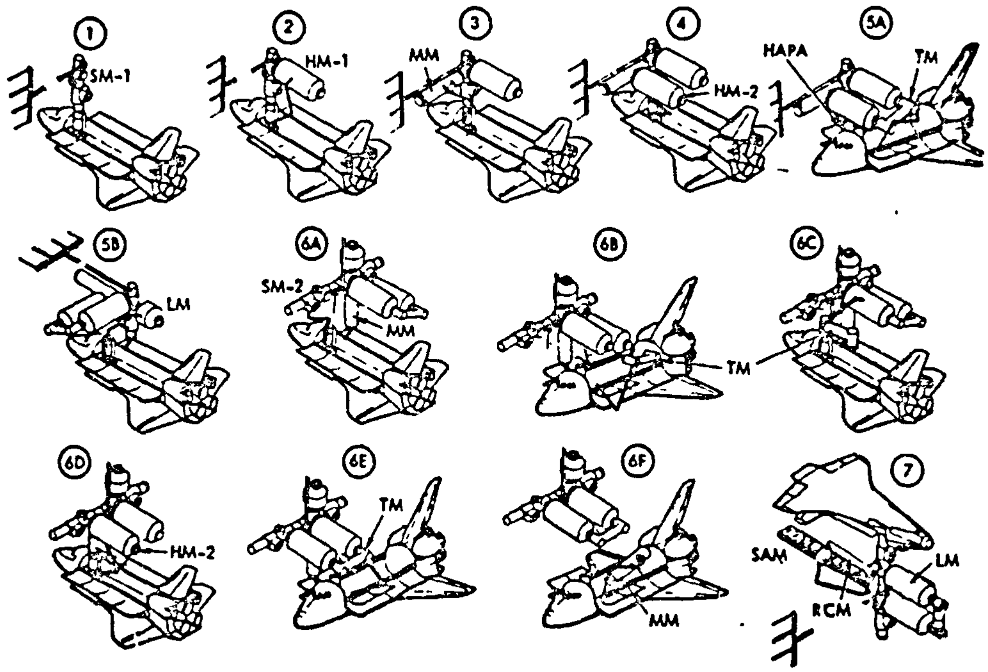

FIGURE 3.10 SOC ASSEMBLY - EVOLUTIONARY SCENARIO 1

TABLE 3.6 SOC ASSEMBLY - EVOLUTIONARY SCENARIO 2 BUILDUP SEQUENCE

EVOLUTION				MODULE	CONFIGURATION 1	2	3	4	5	6	7	8
		SHUTTLE TENDED BASE	LEO PLATFORM	SM-1	X	X	X	X	X	X	X	X
				MM		X	X	X	X	X	X	X
				HM-1			X	X	X	X	X	X
	PERMANENT MANNED BASE			HM-2				X	X	X	X	X
				TM					X	X	X	X
				LM					X	X	X	X
FULLY ASSEMBLED SOC				SM-2						X	X	X
				SAM							X	X
				R/CM							X	X
				CF								X

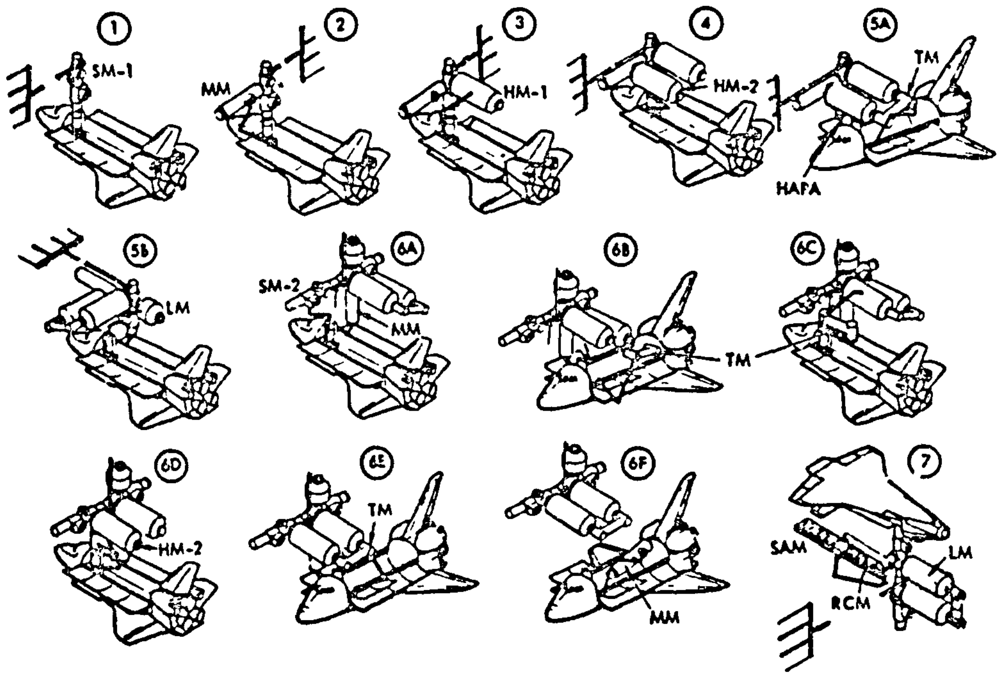

FIGURE 3.11 SOC ASSEMBLY - EVOLUTIONARY SCENARIO 2

revisits. An independent environmental control and life support system (ECLSS) for each of the habitation modules and a clocking capability on the TM adapter are also required to accommodate maximum planning flexibility. Both orbiter and SOC provisions are illustrated in Figure 3.12.

It is interesting to note the significance of the timing of the RCM installation to the SOC buildup. The RCM with its manipulator arm is a very feasible tool which can aid effectively in the assembly of SOC. This conclusion was verified by the 1/48 scale models. By simulating the SOC buildup with the 1/48 scale model, a high-confidence technique is proposed for the assembly of the SOC modules.

SOC Assembly Visibility

An analysis of lighting and TV requirements for the initial assembly operations of the SOC was conducted to determine what features should be incorporated into the SOC and to define potential orbiter impacts. The SOC impacts resulting from the analysis included a concept for installation of a TV camera and a light (or lights) on one side of each berthing port, with a target on the mating side (up coming module). This concept is shown in

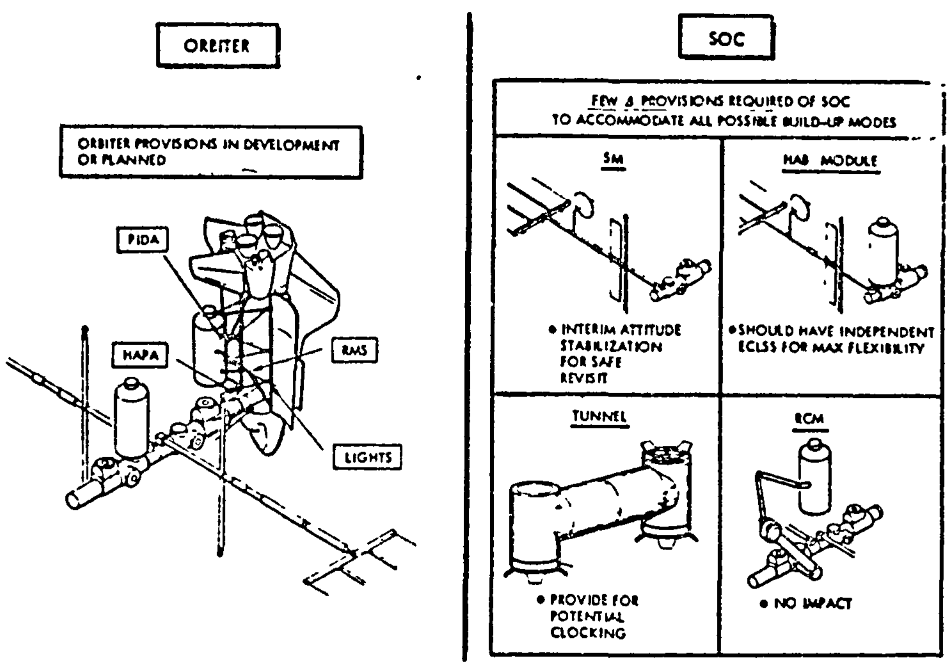

FIGURE 3.12 PROVISIONS FOR SOC ASSEMBLY

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Figure 3.13. In addition, the recommendation includes four exterior flood lights on the RCM cabin, a movable (tilt and pan/TV camera and light set on the RCM manipulator wrist and elbow, and approximately 45 small, colored marker lights distributed around the extremities of the SOC. The latter includes four marker lights on each of three orbiter docking ports.

Recommended minimum changes to the orbiter include a movable lamp on the aft bulkhead of the cargo bay, two movable TV cameras and lights on the aft sides of the docking module exterior and a TV camera and light(s) in the docking port. The proposed locations for all lights, cameras targets are summarized in Figure 3.14. Note that if a handling and positioning aid is used as proposed in some alternate schemes, a TV camera and light are also recommended for the attach port.

The peak power requirements estimated for the orbiter cargo operations could be as high as 4.5 to 6.1 kW, while the SOC peak power for lighting and TV near the end of the buildup sequence could require up to 6.6 kW. It was presumed that SOC power would be available to support its own lighting, TV and RCM operations from (at least) a partially deployed solar array after the first flight in the assembly sequence.

Other design features which can enhance the versatility and enlarge the range of early SOC applications are the use of independent life support systems in the two habitability modules and the incorporation of "docking" capability in the tunnel assembly for joining habitable volumes.

Thus, it is concluded that the SOC design concept can and should have the versatility to accommodate a wide range of evolutionary build plans.

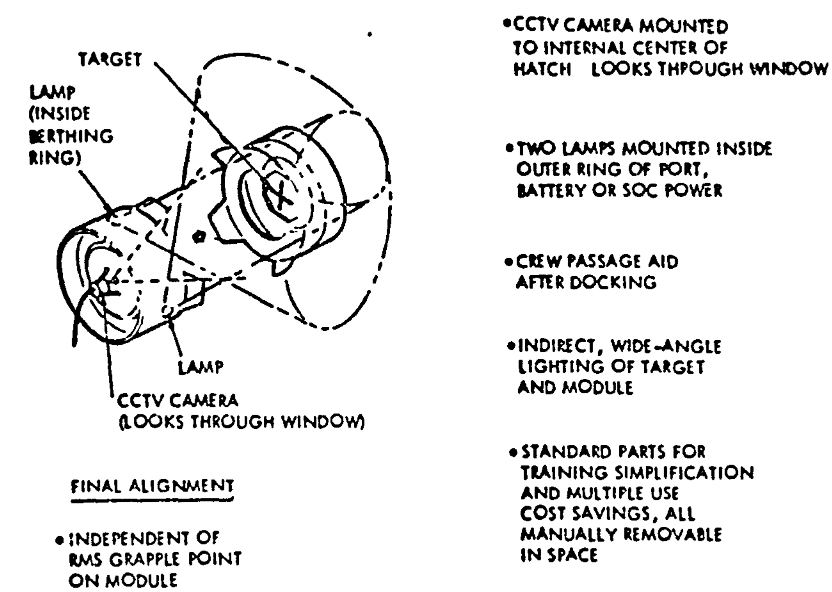

FIGURE 3.13 CONCEPT FOR BERTHING PORT LIGHTING/TV AND TARGET KIT

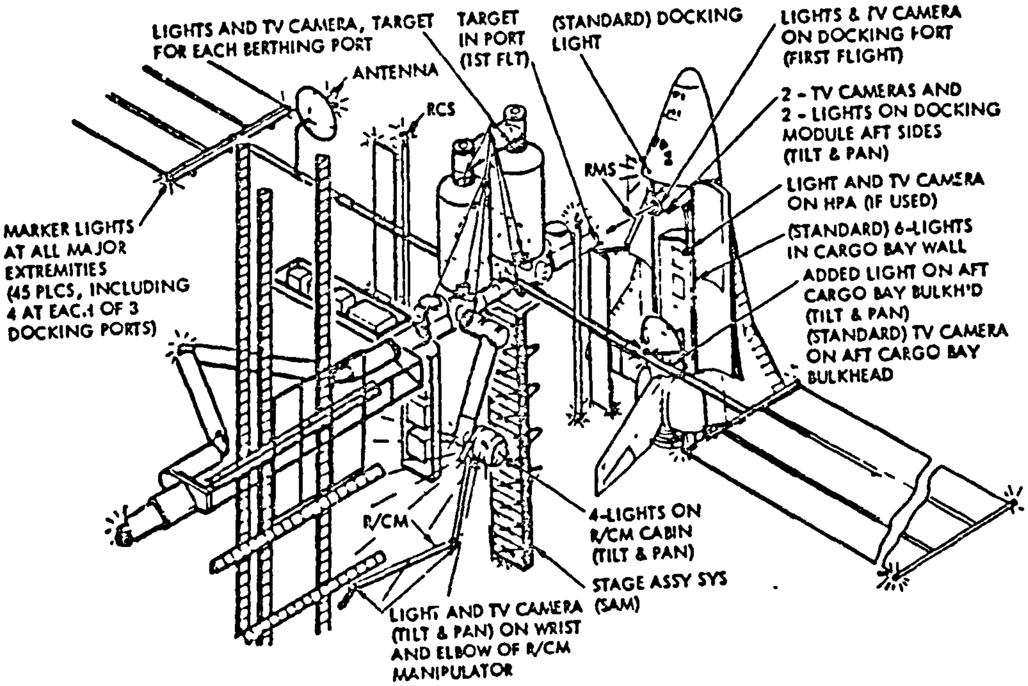

FIGURE 3.14 LIGHTING AND TV CAMERAS FOR SOC ASSEMBLY

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4.0 SOC RESUPPLY & FUEL TRANSFER

This task consists of two subjects as indicated by the heading. The SOC resupply task was concerned with the resupply of logistics to support the normal operations of the SOC and the logistics required for construction and flight support operations. The fuel transfer task concentrated on the transfer of propellant for servicing an OTV.

The objective of this task was to determine the requirements imposed on the SOC and on the orbiter to support the SOC resupply logistics operations for the normal housekeeping and operational activities, and to determine the impacts associated with the transfering of propellant from the orbiter to SOC storage or directly to an OTV.

4.1 SOC RESUPPLY

The SOC resupply issues were concerned with the development of the SOC logistics module (LM) exchange procedure, and the capability of the orbiter to transport a full SOC crew of eight.

<u>No Special Equipment Required to Exchange SOC LM</u>

The development of a logistics module exchange procedure was necessary because a single attach port only was dedicated to accommodate the logistics module (LM). Consequently, the attach port must be vacated before a full logistics module is installed. This requirement necessitates the incorporation of a parking/holding position for either the empty or the full LM during the exchange operation. The utilization of the handling and positioning aid (HPA) located on the right side of the orbiter on the forward section of the payload bay longeron very adequately accomplishes this parking/holding requirement. Figure 4.1 illustrates the use of the HPA for this operation. The HPA has been identified as a necessary device for SOC assembly and for holding construction projects during assembly (Reference 6). Consequently, at this time the HPA can be considered as a piece of equipment that is part of the standard available equipment for space operations.

The orbiter RMS has the reach and motion capability necessary to perform the LM exchange procedure. The exchange procedure, schematically illustrated in Figure 4.1, consists of the extraction of the LM, by the RMS, from the orbiter payload bay and placing it on the HPA in a holding position. The RMS then removes the spent logistics module from the SOC and returns it to the orbiter payload bay. The full LM is removed from the HPA, transported, and berthed to the vacated, dedicated, LM port. The utilities interfaces are remotely actuated as described in Section 2.0 to complete the LM exchange procedure.

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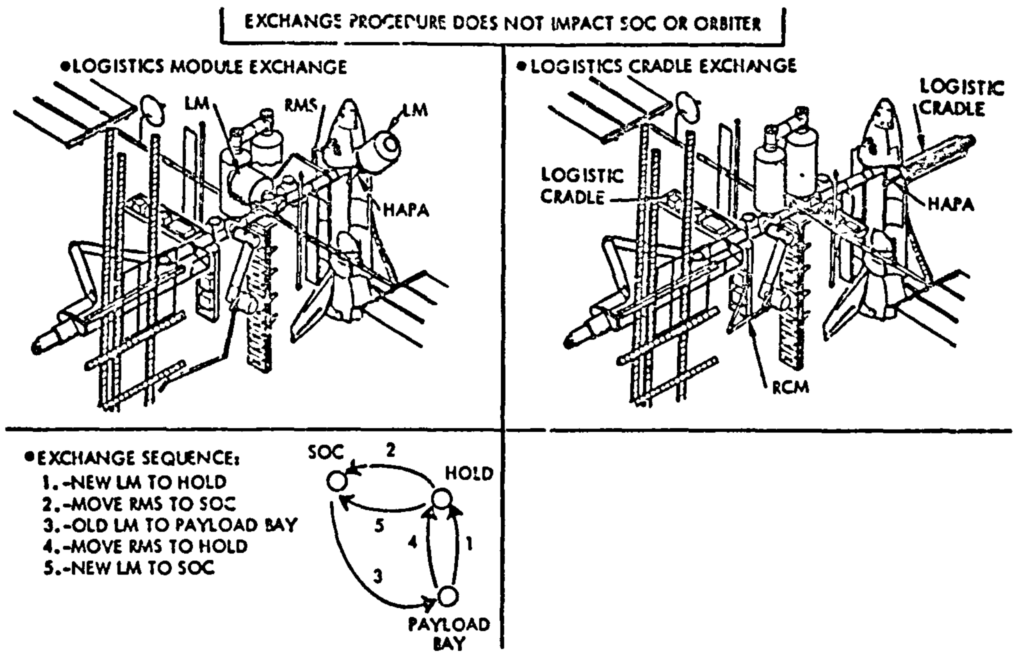

FIGURE 4.1 LOGISTICS MODULE EXCHANGE PROCEDURE

No Special Equipment Required to Install or Exchange Construction and Flight Support Logistics Cradles

Similar module exchange conditions exist for handling of logistics cradles containing space construction materials. The exchange procedure is identical to the SOC LM exchange procedure previously described and illustrated in Figure 4.1. The HPA is again used as a parking/holding device for the cradle. However, because of the long reach necessary to deposit a construction cradle at the construction site, the SOC remote control manipulator (RCM) must perform the transportation phase of the exchange procedure. Consequently, no additional/special equipment is required to support this logistics cradle exchange.

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The Orbiter Can Transport a Full Crew of Eight

Various scenarios can be generated that require the transportation of eight crew persons to and from the SOC. The orbiter as the transportation vehicle must provide this capability. Three orbiter arrangements were considered to verify the orbiter capability, Figure 4.2. The standard cabin seating arrangement has accommodations for 10 people in a rescue mode. If the operation of the orbiter is assumed to be accomplished by the commander and pilot only, the eight remaining seats can be occupied by the SOC crew. However, if the mission on which the crew is being transported requires three or four orbiter crew, then one or two additional seats must be provided in the mid deck section of the cabin. These additional seating positions can be accommodated by removing appropriate portions of the forward modular locker stowage compartments with the airlock inside the cabin. If the airlock is moved outside the cabin or the docking module is acting as an airlock, the modular storage lockers can remain.

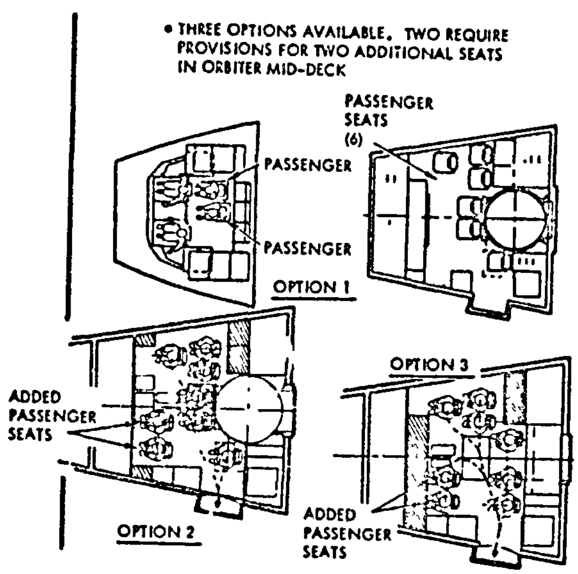


FIGURE 4.2 SHUTTLE CREW TRANSPORT OPTIONS

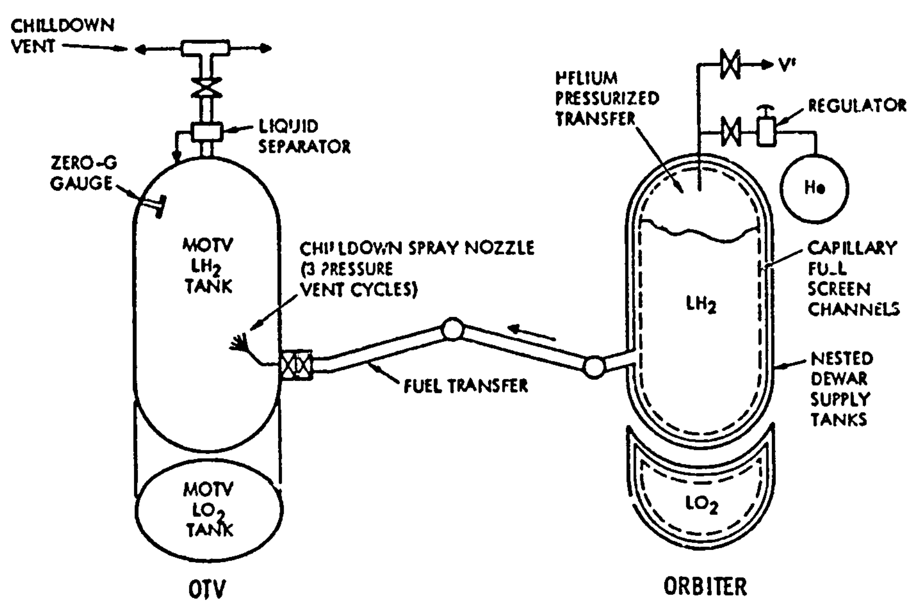
Adequate storage for personal belongings and for emergency provisions appear adequate for all arrangements investigated. Clear paths for emergency exit for a bad abort condition are also available. Additional analysis and tests are necessary to positively verify the emergency egress procedures. However, this preliminary analysis indicates the feasibility of the orbiter to transport a full crew of eight to or from the SOC.

4.2 FUEL TRANSFER

The fuel transfer analysis evaluated the fuel transport and transfer concept developed by the General Dynamics Corporation as it would apply to this SOC operation. Suggested improvements/revisions were defined as appropriate for the SOC operation.

<u>Low-Risk Technology Is Available For Zero-G Fluid Transfer</u>

A conservative system design, based partly on concepts recommended by General Dynamics in Reference 1, was developed for zero-g transfer of LO_2 and LH_2 from the orbiter to OTVs berthed on SOC (Figure 4.3). The features of this system include a dewar-type supply tank in the orbiter, helium pressurized transfer, capillary screen-channel propellant acquisition, and pressure/vent cycling for prechilling of the LH_2 receiver tank. Overall propellant losses, from ground loading to OTV propulsive usage, were estimated to be approximately 7.5%.



NOTE: LO_2 TRANSFER SYSTEM SAME AS LH_2 EXCEPT NO CHILLDOWN VENTING

FIGURE 4.3 SOC-GDC BASELINE REFUEL SCHEMATIC

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Advanced Concepts Can Substantially Reduce Transfer Losses

An advanced transfer system concept, Figure 4.4, was also developed which has the potential of reducing overall losses to less than 2.5%. This includes a number of candidate refinements such as a lightweight supply tank with multi-layer insulation (MLI) instead of the heavier dewar, subcooling of propellants to reduce boiloff losses, pump transfer for reduced tank pressure requirements, autogenous pressurization to reduce pressurization system weight, non-venting pre-chill of the receiver tanks to eliminate chilldown losses, simplified capillary devices to reduce tank cost and weight, and centralized SOC transfer control.

The technique recommended for zero-g propellant guaging is acoustic resonance, Figure 4.5, with ullage compliance and RF guaging retained as fall back approaches.

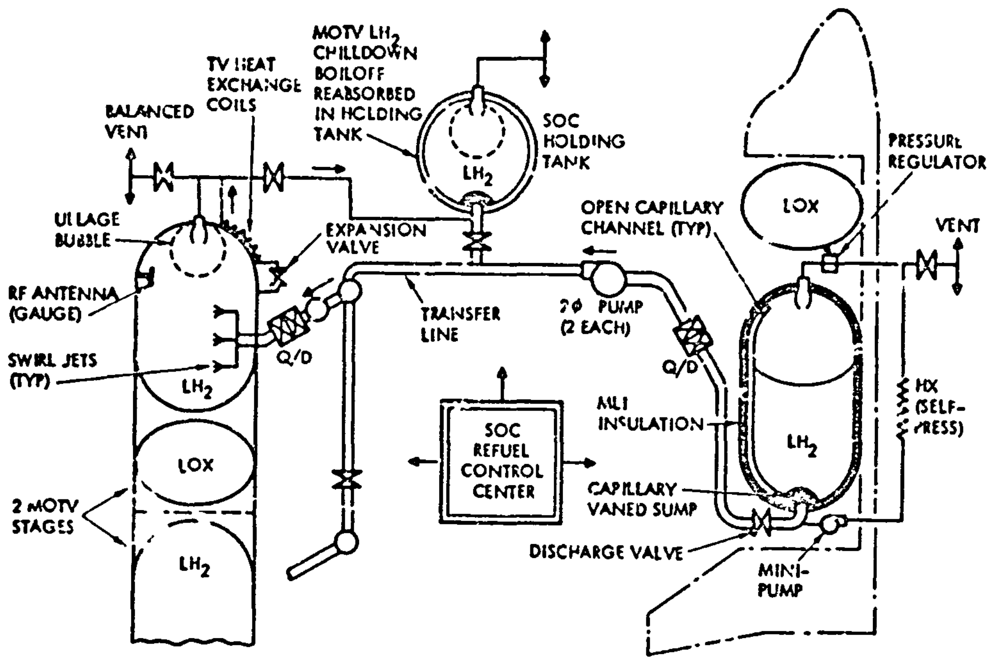

FIGURE 4.4 ROCKWELL SOC REFUELING SCHEMATIC

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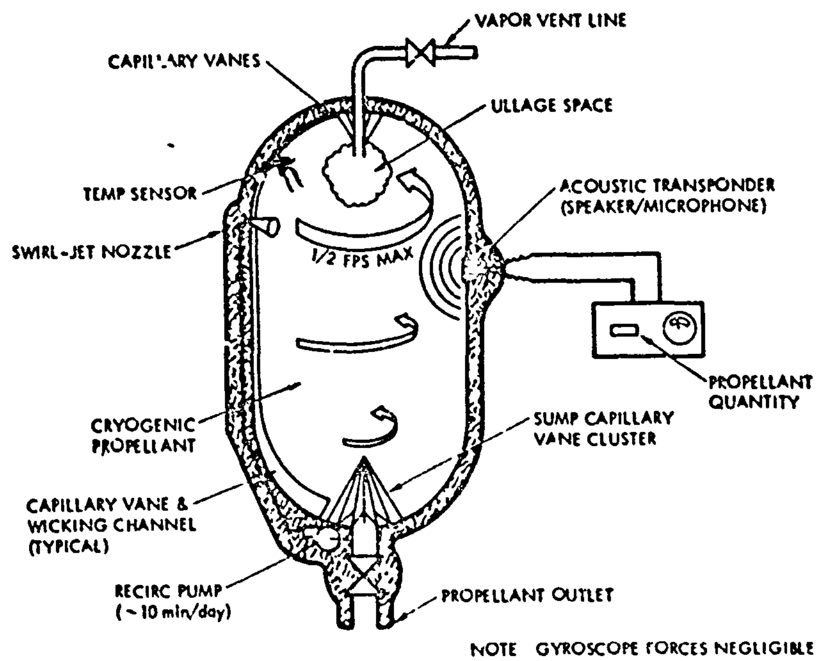

FIGURE 4.5 ZERO-G CRYOGENIC TANK GAUGING AND PROPELLANT POSITIONING SYSTEM

4.3 OTHER FLUIDS TRANSFER

Remote Controlled Fluid Transfer Is Viable

For fluids which require resupply on a regular basis, e.g., LOX, LH_2 and hydrazine, transfer by means of a remotely operated disconnect through a single filling point into one or more stowage tanks on SOC is the recommended mode of resupply. This approach minimizes EVA requirements and the hazards associated with exposure to spillage and leakage. For fluids requiring infrequent resupply, such as fluorocarbons, container replacement using the RCM and manually operated disconnect fittings is considered a practical approach.

4.4 PROPELLANT STORAGE

Recovery of ET Propellant Residuals and Storage on SOC Shows Major Benefits

An analysis was made of cryogenic propellant storage on SOC, in combination with sub-orbital recovery of residuals from the Shuttle External tank (ET), Figure 4.6, and propellant payload sharing on under-loaded orbiter flights. The results indicated that a drastic reduction (1/3 to 1/2) can be achieved in the total number of Shuttle launches required for a typical yearly SOC traffic schedule.

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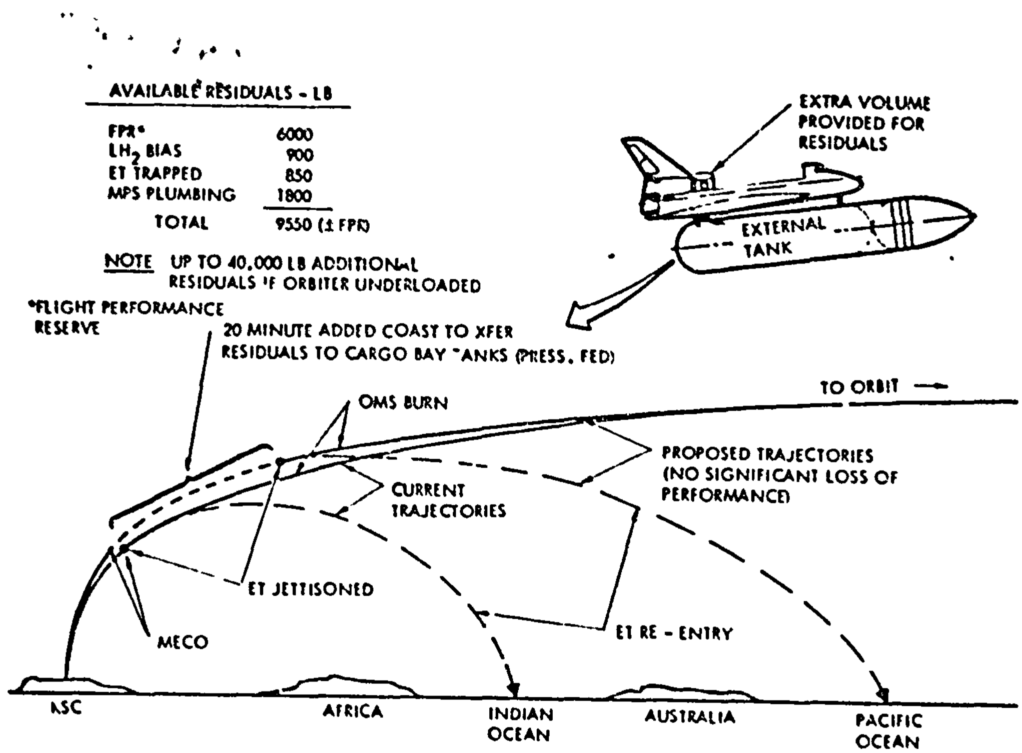

FIGURE 4.6 MODIFIED TRAJECTORY CONCEPT FOR ET PROPELLANT RECOVERY

OTV Propellant Storage on SOC Is Recommended

The potential benefits obtained from providing propellant storage capability are indicated in Figure 4.7. The ability to store OTV propellants on the SOC can save on the number of propellant logistics flights required to support OTV operations. These savings result from (1) the recovery of ET unused propellant, (2) the elimination of "round-off" flights - propellant needed for a given OTV mission above an integer number of Shuttle flights, and (3) basic reductions in overall OTV propellant requirements which can be achieved through lightweight space based OTV designs. Further savings would be possible through reduced propellant losses by incorporating active refrigeration into the propellant storage facility.

Second, propellant storage on SOC could also uncouple Shuttle logistics from SOC based OTV operations. Instead of requirements for breaking into the Shuttle manifesting plan for a cluster of three, four, or possibly five closely spaced flights in support of an MOTV mission, the propellant could be delivered to SOC on a routine scheduled basis, thus, easing fleet management and potentially improving fleet utilization. Propellant storage could also provide a rapid response capability for rescue and/or other high value services.

Because of these major benefits, OTV propellant storage on SOC is recommended.

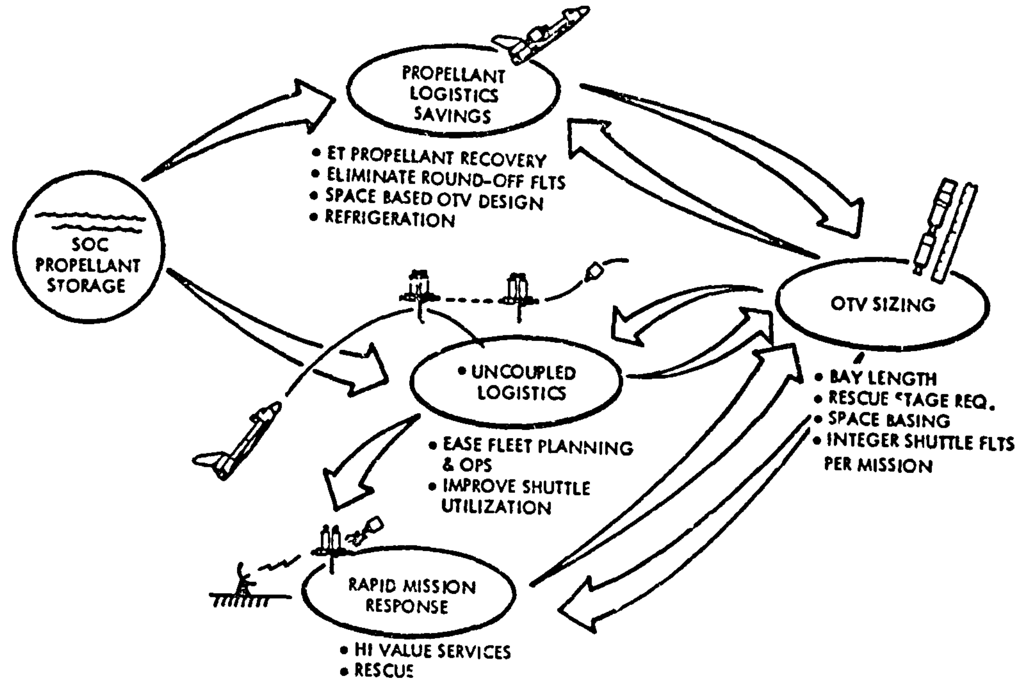

FIGURE 4.7 SOC PROPELLANT STORAGE - POTENTIAL BENEFITS

Active Refrigeration Is Feasible

Analysis shows that active refrigeration of the above LOX and LH_2 storage tanks on SOC is practical and beneficial in terms of reducing storage losses and providing subcooled propellant. The latter can improve OTV structural mass fraction and reduce mission boiloff losses. It is particularly attractive in conjunction with the recovery of residual propellants from the Shuttle ET. Figure 4.8 indicates a tank refrigeration concept that utilizes a Brayton Turbo Refrigeration System in conjunction with a refrigeration shield concept. The power requirement for this arrangement would be in the 1 to 2 Kw range.

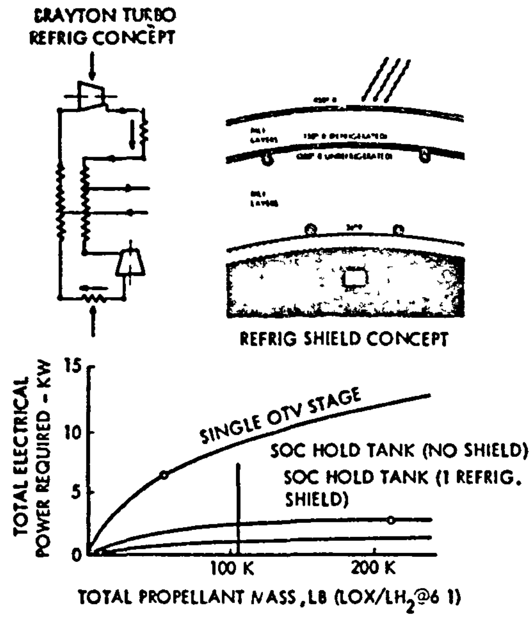

FIGURE 4.8 PROPELLANT STORAGE REFRIGERATION CONCEPT

5.0 FLIGHT SUPPORT FACILITY

Three principal objectives are identified for this task; (1) determine the implications to the SOC to perform the activities associated with spacecraft assembly, launch, recovery and servicing, (2) determine the implications to the Shuttle to perform these same activities, and (3) to determine the unique requirements imposed on the space vehicle to permit these space based activities.

This section is composed of the subjects of the servicing philosophy associated with space based servicing activities, the SOC arrangement concept providing these services; the Shuttle implications when performing similar functions before SOC is available and the unique requirements imposed on the spacecraft to permit space based servicing.

5.1 SUMMARY

Servicing Philosophy

A servicing philosophy is developed that addresses servicing of an MOTV/OTV. In general, the philosophy is modeled after airline type practice where maintenance (LRU replacement) is performed only as a result of indicated deteriorating performance, failure of redundancy, wear, or when the time/cycle of critical equipment is scheduled for replacement. This philosophy avoids the replacement of a good operating unit when its performance history does not warrant it. The incorporation of warehousing facilities on the SOC to store spare parts principally for planned replacement, but also for unplanned critical parts was identified. The concept of utilizing replaceable system packages, similar to the multi-mission system packages, mounted to the external surface of the space vehicle is recommended. This concept permits removal/replacement by remote or EVA methods.

The philosophy also identified the desirability of providing dedicated positions for the maintenance activities, particularly for the unscheduled activities. The unscheduled positions can also be utilized for the storage of large spacecraft elements. Both the scheduled and unscheduled maintenance positions have the flexibility to be utilized for either function as the flight and maintenance rates dictate. The implementation of this philosophy is represented in the flight support facility configuration concept presented herein.

A major element of the servicing philosophy was the method by which functions were allocated to man or machine. Basically, operational and environmental constraints of a particular function were considered along with the relative capabilities of man and machine to perform the function. As development of the Flight Support Facility configuration progressed, these considerations were applied whenever allocation questions were encountered and, thereby, contributed toward the final arrangement.

Versatile Multiple Servicing Functions Capability

The development of a Flight Support Facility configuration was based on a detailed assessment of the activities that are required to accept a returning MOTV, inspect it, service it and prepare it for another mission. Those activities that were found to impact the configuration of the Flight Support Facility were further analyzed to determine the extent of the impact. Essentially, the analysis of each significant activity resulted in the selection of a preferred method to perform the activity by evaluating two or more optional concepts. Also resulting from the analysis were a listing of the support equipment required to perform the activity, the extent of crew involvement, and the identification of impacts to the configurations of the SOC, the OTV and the Shuttle.

The arrangement of the Flight Support Facility evolved into a versatile facility providing multiple servicing functions capability. It consists of two major components; the Service Control Center and the Service Fixture as shown in Figures 5.1 and 5.2. The Service Control Module is a cylindrical shaped pressure vessel that controls, monitors and operates all the functions of the Flight Support Facility. Externally, it features three docking/berthing adapters that interface with the SOC, the Service Fixture and the crew module of the MOTV.

The Service Fixture has a hexagonal cross-section to provide six surfaces on which assembly, staging and servicing operations can be performed. Scheduled and unscheduled maintenance stations can be accommodated as well as storage of large equipment or space vehicle elements. Its major features include two mobile manipulators, docking port, carrier assemblies and warehousing provisions.

The mobile manipulators are supported on two of the four translation rails system that are part of the Service Fixture as shown in Figure RST-3. With a length approximating that of the orbiter RMS, the manipulators can reach all areas requiring service on tandem stage OTV or a parallel tank OTV as illustrated in Figure 5.3. On the other two translation rail systems, carrier assemblies are mounted to support the OTVs during assembly, servicing, and maintenance operations. As illustrated in Figure 5.4, each carrier assembly consists of a PIDA adapter mounted on a transporter plate and driven by four motors to provide a measure of redundancy.

Two warehousing compartments are included in the Service Fixture to store LRUs, spare parts, tools and special equipment. There is sufficient space to mount seven LRUs, each 1m x 1m x .45m in size, on each of two bulkheads per compartment as seen in Figure 5.5. Operational aspects of the warehousing provision can also be seen in Figure 5.5, where a swing arm inside the compartment removes the LRU from its mounts and hands off to one of the mobile manipulators through one of two access doors. Subsequently, the manipulator translates the LRU to the proper location on the OTV and installs it.

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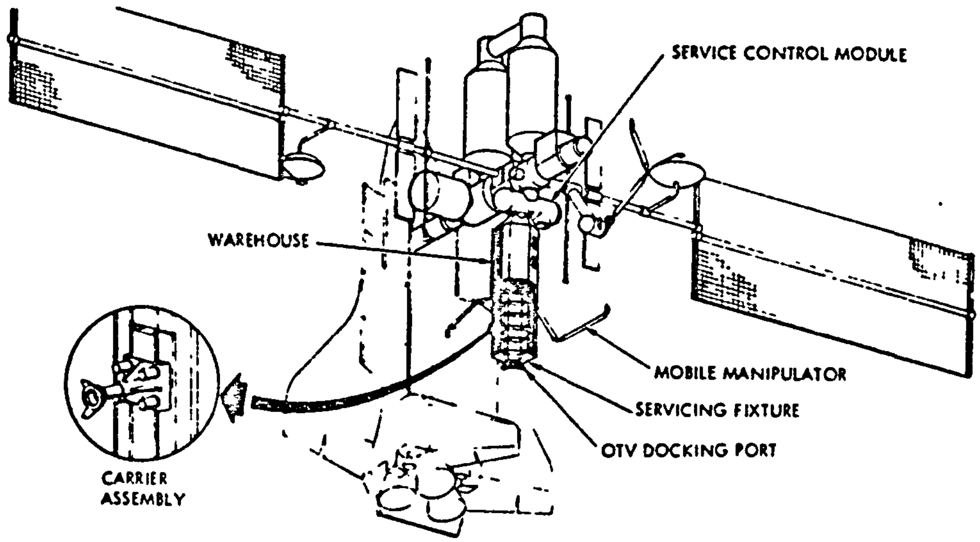

FIGURE 5.1. INITIAL FLIGHT SUPPORT FACILITY CONFIGURATION

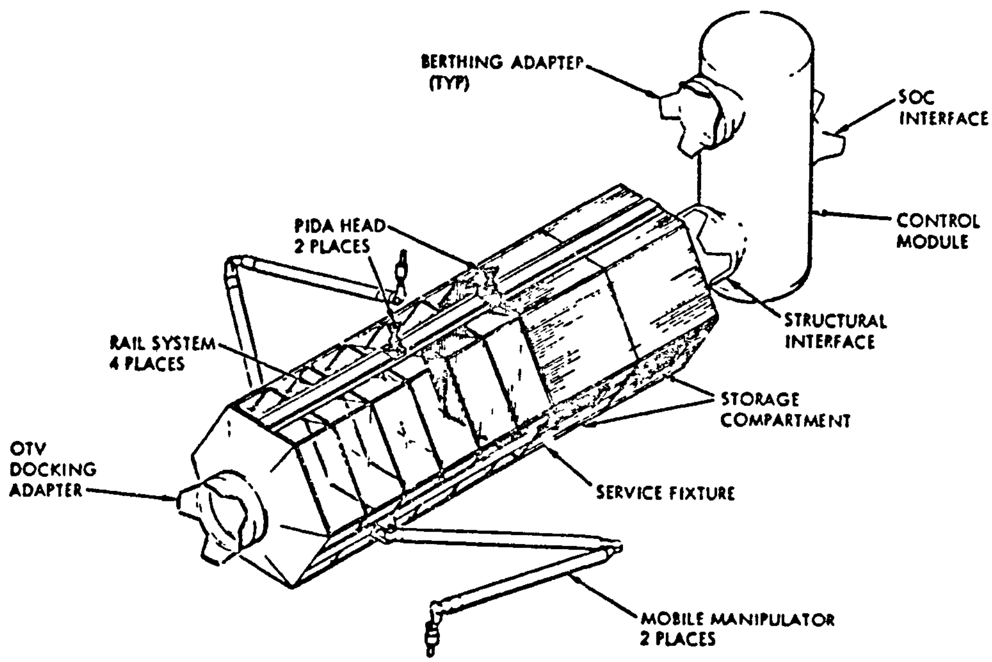

FIGURE 5.2. SERVICE FIXTURE ARRANGEMENT

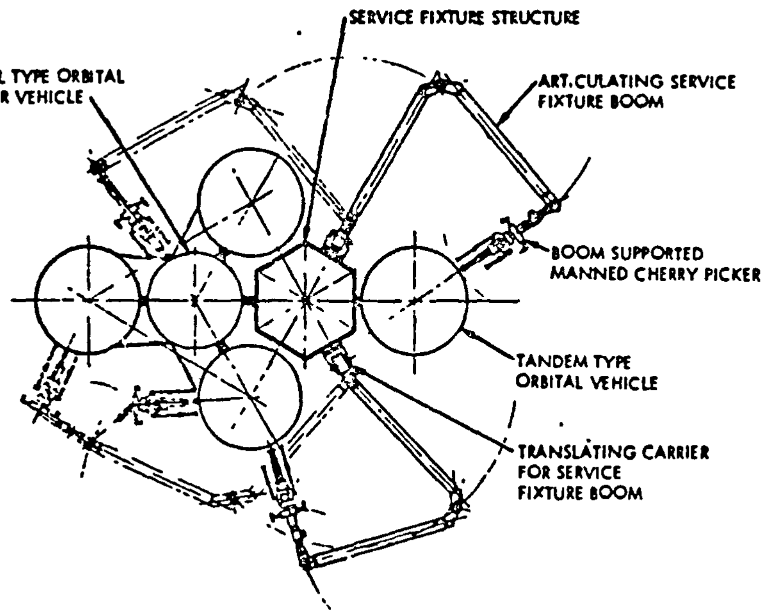

FIGURE 5.3. TRANSLATION RAIL SYSTEM AND MANIPULATOR REACH CAPABILITY

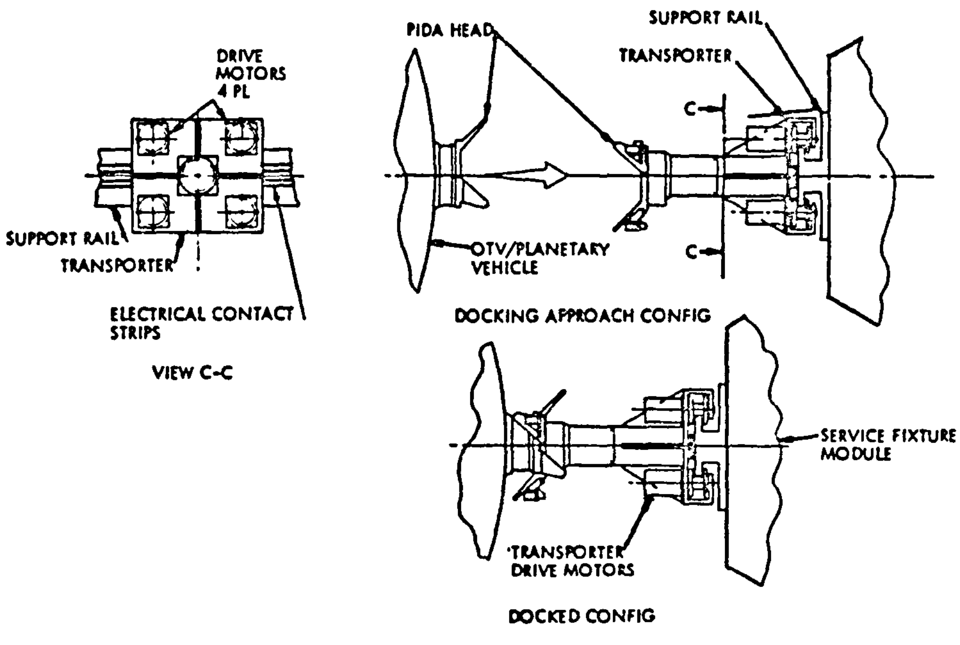

FIGURE 5.4. TRANSLATION RAIL SYSTEM WITH PIDA SUPPORTS

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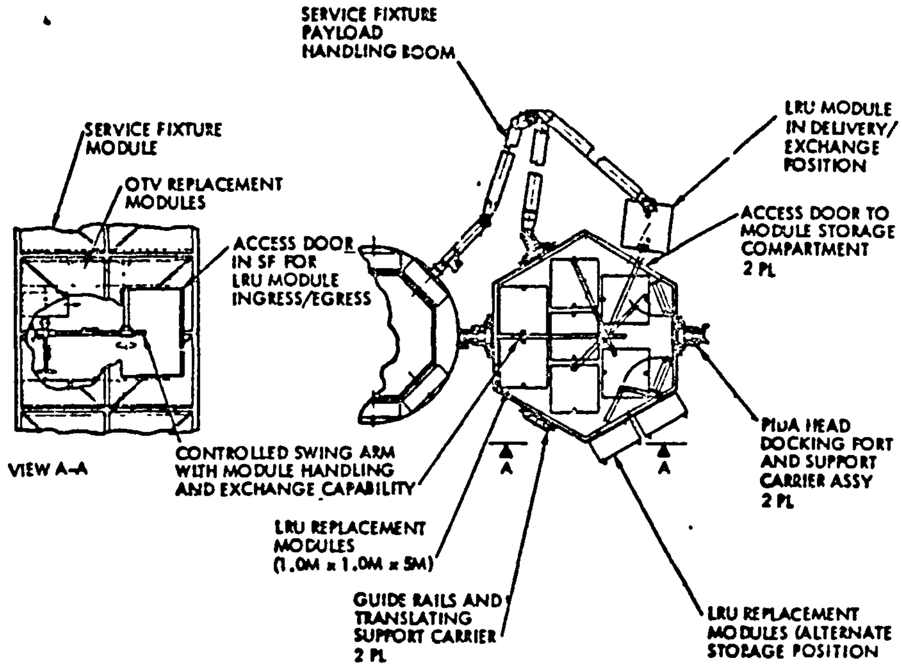

FIGURE 5.5. STOWAGE PROVISIONS

Growth Capability

A servicing facility growth concept was developed. This concept considers that the early SOC operations will be concerned primarily with the assembly and preparation for launch of single stage OTV's with GEO payloads. The OTV's are designed for space based operations and would return for servicing and preparation for other similiar missions. As these activities increase and include MOTV missions the facility can grow to accept the increased activity. The growth is accomplished principally by adding another section of the facility fixture as seen in Figures 5.6 and 5.7. Additional growth facilities such as propellant storage can also be added when appropriate. This propellant storage facility is independent of the servicing fixture growth and thus can be added at any phase of the SOC servicing facility growth.

OTV Operations From the Shuttle

Prior to SOC operations, the launch, recovery and servicing of an OTV from the Shuttle may be desireable. The analysis of this type of operation for an OTV designed to operate from the SOC indicated that the characteristics required of the OTV to be serviced from the SOC will permit similar servicing operations from the Shuttle. The Shuttle docking module and RMS provide the holding and maneuvering activities. An adapter to the docking module to hold the OTV for the installation of the payload is

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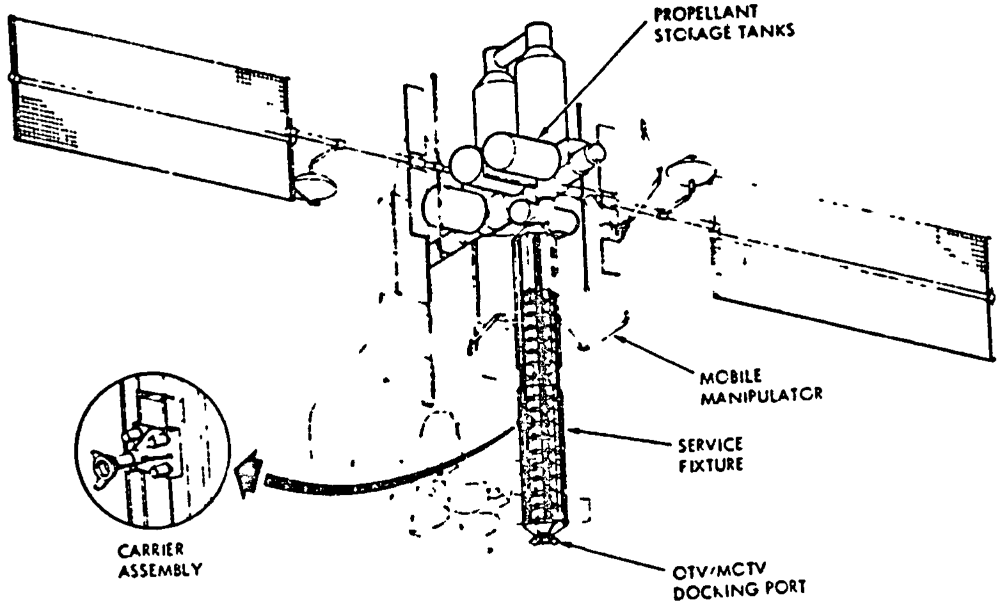

FIGURE 5.6. FLIGHT SUPPORT FACILITY -- GROWTH CONFIGURATION

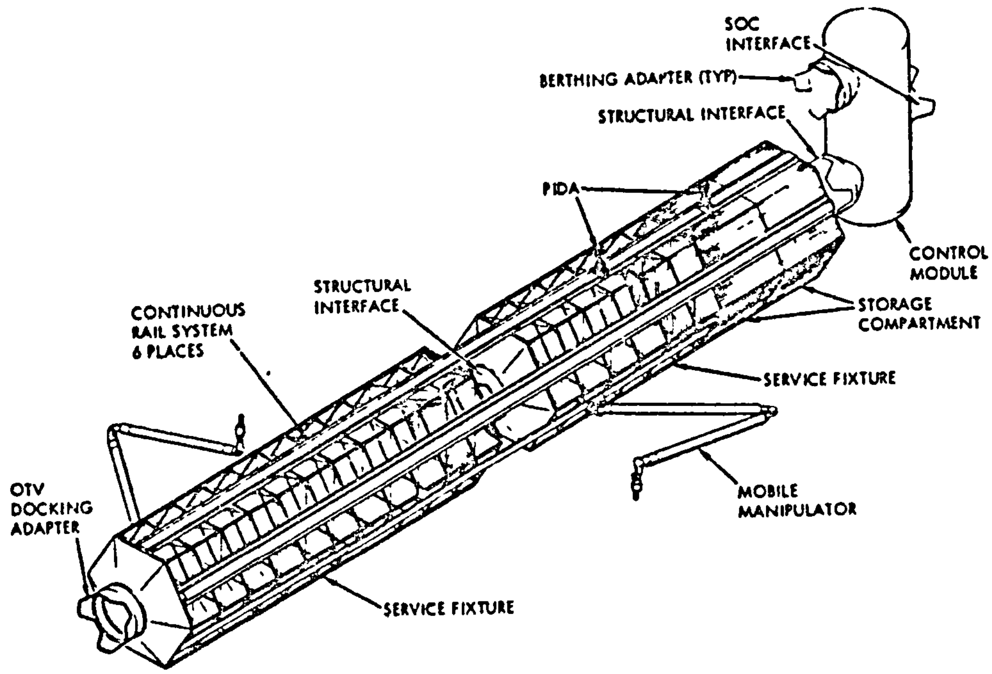

FIGURE 5.7. TANDEM STAGE PROVISIONS

identified as shown in Figure 5.8. The adapter provides the capability to orient the OTV stage to assist in mating the payload. The OTV stage utilizes a standard berthing port at the forward end for mating of the payload. The PIDA attachments on the OTV provide for the controlled deployment from the payload bay and will also provide a mating point to the docking module adapter.

5.2 IMPLICATION OF THE FLIGHT SUPPORT FACILITY

From the final arrangement of the Flight Support Facility, the implications to the SOC, the OTV and the Shuttle were determined to be feasible modifications that can be incorporated adequately with the proper planning. The implications to the SOC and OTV are discussed below. The implications to the Shuttle were, fortunately, minimal. The role of the orbiter in the servicing operations is limited to transporting payloads, propellant tanks and other large OTV elements to SOC and these tasks do not require additional provisions beyond those supplied for any other type of payload.

5.2.1 Implications to SOC

The implications to the SOC for supporting OTV associated assembly, servicing and maintenance activities are summarized in Table 5-1. Relocation of the Flight Support Facility to the second pressure volume of SOC was required to eliminate a potential interference between the Service Fixture and vertical fin of the orbiter. The interference was potentially possible if the 6° docking tolerance was imposed during docking of the orbiter to the SOC. The only feasible relocation port was previously

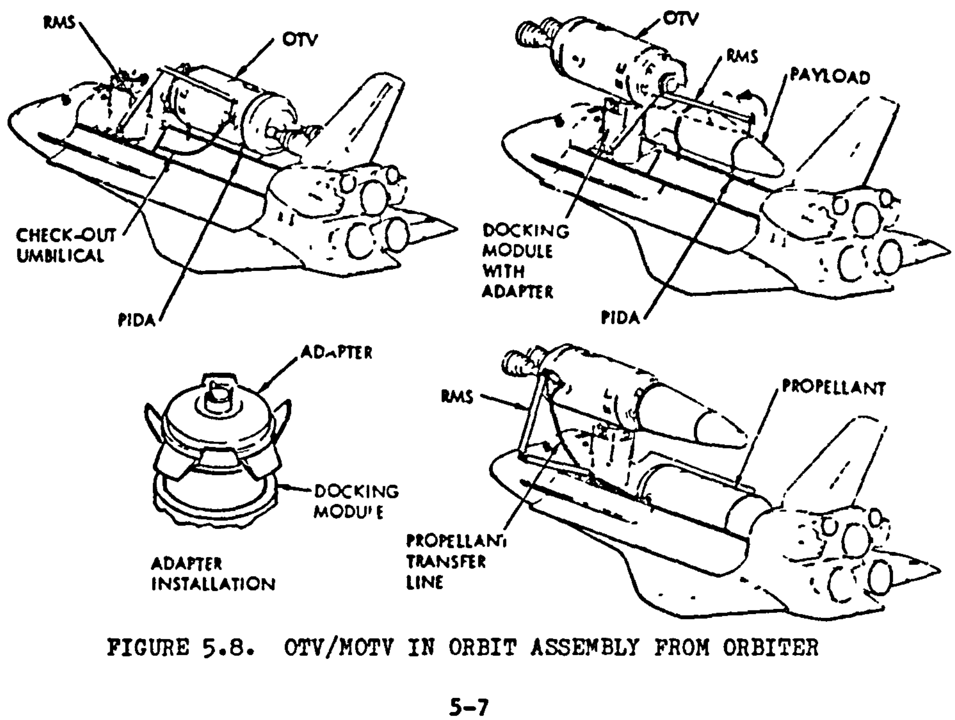

FIGURE 5.8. OTV/MOTV IN ORBIT ASSEMBLY FROM ORBITER

TABLE 5-1. IMPLICATIONS TO SOC

- RELOCATED FLIGHT SUPPORT FACILITY TO SECOND PRESSURE VOLUME OF SOC
- ADDED SERVICE CONTROL CENTER
- ADDED PROPELLANT STORAGE TANKS
- ADDED SECOND SERVICING FIXTURE SECTION FOR TANDEM STAGE OTV SERVICING
- SERVICE FIXTURE INCLUDES
  - TWO MOBILE MANIPULATORS
  - TWO STORAGE COMPARTMENTS
  - TWO TRANSLATION RAIL SYSTEMS WITH PIDA ADAPTERS
  - TWO DOCKING/BERTHING PORTS
  - SERVICING INTERFACES

designated as the MOTV port. To accommodate both the MOTV and the Service Fixture, a pressurized adapter was added to the SOC and designated as the Service Control Center.

5.2.2 OTV Implications

The unique requirement imposed on the OTV to permit space-based servicing and maintenance activities are summarized in Table 5-2. The standard berthing adapter is required to allow the OTV to dock with the Service Fixture and, subsequently, to berth to the Service Control Center for crew exchange. The PIDA attach provisions are utilized for berthing the OTV on the Service Fixture as well as for deploying the OTV from the Orbiter payload bay when it was initially delivered to the SOC. Externally mounted LRUs facilitate their removal and installation by maximizing their accessibility for remote or EVA operations.

TABLE 5-2. OTV IMPLICATIONS

• STANDARD BERTHING PORT AT FORWARD END
• TWO PIDA ATTACH PROVISIONS ON BODY
• GRAPPLE FITTINGS TO ACCOMMODATE RMS
• EXTERNALLY MOUNTED SUBSYSTEM PACKAGES (LRU)
• ELECTRICAL UMBILICAL INTERFACE
• PROPELLANT FILL INTERFACE
• HYDRAZINE & HELIUM FILL INTERFACES

6.0 CONCLUSION

This section summarizes the conclusions that have resulted from the five basic tasks. The conclusions are organized by the SOC program elements rather than by tasks. The conclusion statements will emphasize the implications to the SOC, to the Shuttle, and to an OTV. The unique equipment required to support each of the elements is also included.

6.1 SOC IMPLICATIONS

- Fly a variable altitude to optimize Shuttle Logistics Delivery
- All module mating interfaces and other potential mating interfaces to be a "standard" configuration
- All interface ports to be "passive" - no active attenuation
- Provide appropriate location and number of RMS grappling points for all SOC modules and assemblies
- All modules to have two PIDA attach points for cargo bay deployment
- All hatches at berthing interface to contain a window and provisions for mounting a TV camera for berthing alignment viewing thru window
- Provide mounting for two lights within interface port for alignment target viewing
- Accommodate provisions on exterior of interface hatches for mounting alignment target
- Provide adequate CMG and RCS control to stabilize untended module assemblies during SOC buildup
- Primary Shuttle mating port to be oriented to permit orbiter tail down orientation
- Provide berthing/docking accommodations for second orbiter on habitable module connecting tunnel at second habitable volume
- SOC to provide fuel transfer control
- Accommodate fuel transfer line on SOC exterior including active orbiter interface segment
- Accommodate propellant storage facility (growth capability)

- Accommodate flight support facility
- Provide lights on RCM cab with tilt and pan capability
- Provide TV and a light on the RCM manipulator wrist and on the elbow both with tilt and pan capability
- Provide colored marker lights at extremities of SOC - approximately 45 required

6.2 SHUTTLE IMPLICATIONS

- Provide accommodations for a docking module interfacing with the Spacelab tunnel adapter
- RMS software modifications required for berthing orbiter to SOC
- Provide accommodations for two PIDA's
- Provide accommodations for a HPA
- Provide accommodations for two additional passenger seats in the mid deck of crew cabin
- Provide tilt and pan light on aft bulkhead
- Provide a HPA to standard mating interface adapter with a fixed light and TV kit

6.3 OTV IMPLICATIONS

- Provide standard berthing port at forward end of OTV and MOTV crew module
- Provide two PIDA attach points on body of OTV for Shuttle payload bay removal and servicing fixture attach
- Provide independent manned module for MOTV missions
- Provide externally mounted systems packages with two point attach provisions
- Provide electrical umbilical for servicing facility interface(s)
- Provide purging facility interface(s)

- Provide propellant fill interface(s)
- Provide engine removal/replacement capability (trade study)
- Provide external insulation removal/replacement capability (trade study)
- Provide other liquid and gas fill umbilical interfaces
- Provide grapple points for manipulator(s) and RMS

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